Contract Report ITL-95-1
June 1995

US Army Corps
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Computer-Aided Structural Engineering (CASE) Report

Comparison of Barge Impact Experimental and Finite Element Results for the Lower Miter Gate of Lock and Dam 26

by Kenneth M. Will, Georgia Institute of Technology

Prepared for Headquarters, U.S. Army Corps of Engineers

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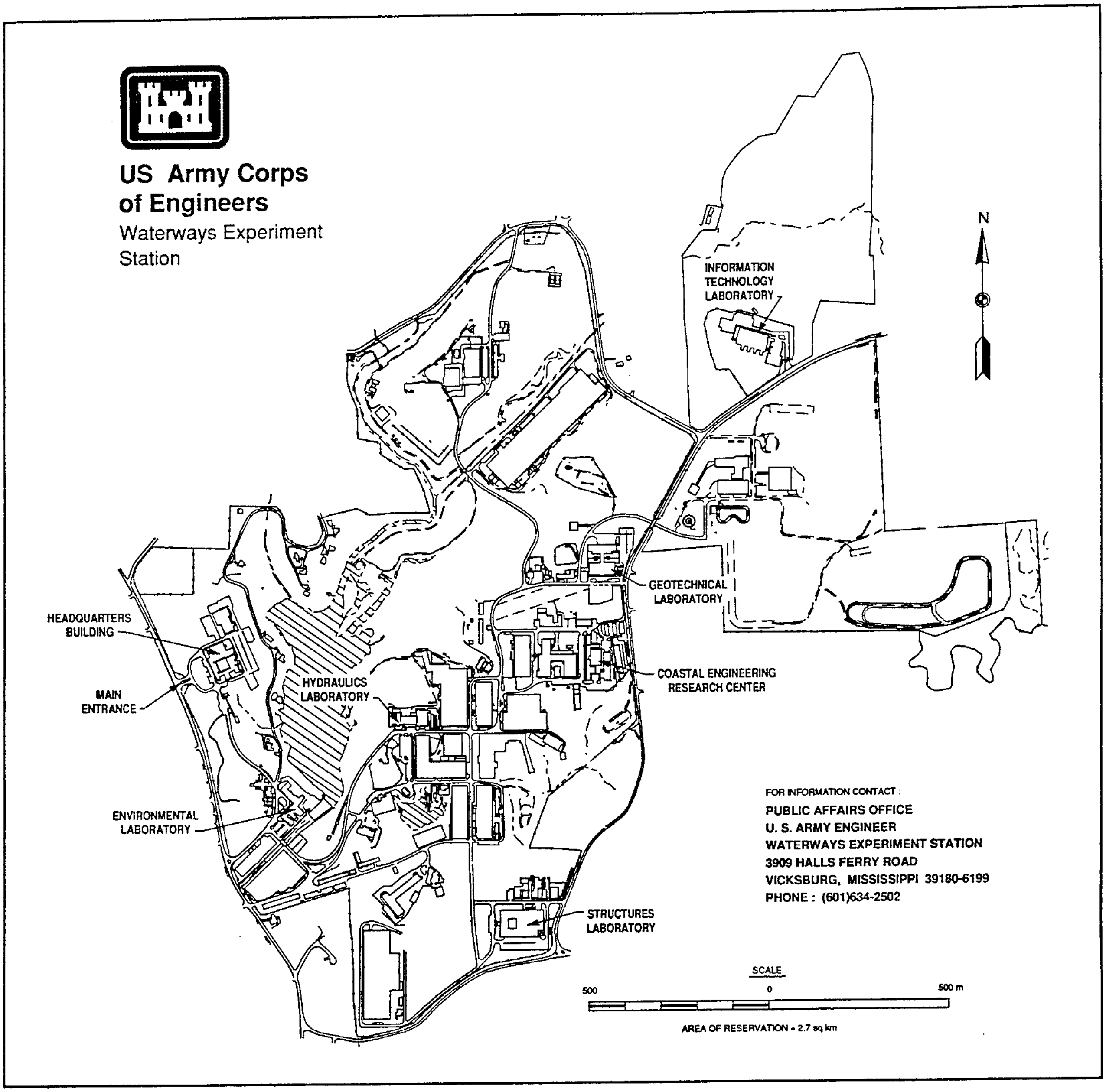

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Contents

Preface

The work described in this report was performed under the Computer-Aided Structural Engineering (CASE) Project. The CASE Project is managed by the Scientific and Engineering Applications Center (S&EAC), Computer-Aided Engineering Division, Information Technology Laboratory (ITL), U.S. Army Engineer Waterways Experiment Station (WES). The CASE Project is funded by the Civil Works Directorate, Headquarters, U.S. Army Corps of Engineers (HQUSACE). Mr. Cameron Chasten, formerly S&EAC, monitored this work under the general supervision of Mr. H. Wayne Jones, Chief, S&EAC, and Dr. N. Radhakrishnan, Director, ITL.

The work was performed by Dr. Kenneth M. Will, Consultant, Georgia Institute of Technology, Atlanta, under USACE contract DACW3991M1917.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters
kips	4448.	newtons
kips per square inch	6.895	megapascals

1 Introduction

Overview

The passing of barges through locks may result in the impact of the barge against one or both of the closed miter gates. The forces resulting from the impact of the barge against a miter gate must be considered in the design of the miter gate. The engineer responsible for the miter gate design must have guidelines as to the magnitude and distribution of this impact force.

Criteria for this barge impact loading is currently given in EM 1110-2-2703 (US Army Corps of Engineers 1984). For horizontally framed miter gates, an equivalent water load of 6 ft minimum is used for loading above the top girder in the design of the skin plate and 10 ft minimum is used below the top girder for the design of the horizontal girders. For vertically framed gates, a 120 kip concentrated load is specified and may be applied anywhere from the miter end to within 10 feet of the lock wall with a 33 percent overstress being allowed. Unfortunately, no supporting documentation is available in EM 1110-2-2703 to support the above criteria. The engineer must assume that these criteria are accurate or at least conservative and use them in the design.

Experimental Testing

The replacement of Mississippi Locks and Dam 26 by the Melvin Price Locks and Dam presented an excellent opportunity to perform an experimental study to study the behavior of barge impact on the lower miter gates. These miter gates were vertically framed. The main purposes of the experimental testing was to obtain strain gage and load magnitude data, and to observe the behavior of the miter gate due to barge impact. There was no head differential on the gates. A series of four progressively increasing impact loads was applied to the miter gates by impacting the gate with a barge tow. The velocity of the impact was varied to generate the increasing impact loads. A summary of the experimental testing program and results may be found in a paper by Chasten, C. P., and Ruff, T., "Miter Gate Barge Impact Testing, Lock and Dam 26, Mississippi River," *Proceedings of the 1991 Corps of Engineers Structural Engineering Conference*, 1991.

Objectives of the Finite Element Study

A primary objective of this study was to develop a finite element model of the lower miter gate of Lock and Dam 26. Once the model was developed, static analyses were to be performed to determine the behavior of the gate.

An initial objective of the study was to perform the finite element analysis of the lower miter gate of Lock and Dam 26 and perform a barge impact static analysis prior to the experimental testing. The purpose of performing this first analysis was to assist the experimental program in the location of the strain gages. Unfortunately, due to the short time that existed before the demolition of the gate and contractual delays, the finite element model could not be developed prior to actual testing.

After the experimental program had been completed and the data analyzed, the primary objective of the study was to determine if the guidelines in the EM 1110-2-2703 were accurate or needed to be modified in order to more accurately reflect the barge impact loading. A finite element model of the miter gate was developed and an analysis performed for an impact at the same location as in the experimental study. The magnitude of the load was the same as recorded in one of the impacts measured in the experimental study. The finite element results were then compared with the experimental strain gage results at several locations in the top girder. If needed, the finite element model was to be calibrated to match the experimental results for further analyses. No calibration was felt to be necessary. Further analyses were then performed for design loading conditions based on the EM criteria for both horizontally and vertically framed gates. These results were compared with hand calculations based on the gate behaving as a three hinged arch. The purpose of these calculations was to determine if the finite element results were reasonable for the additional loading conditions.

Chapter 2 of this report summarizes the finite element model including descriptions of the modelling of the structural elements of the gate, the boundary conditions, and the various loadings. Chapter 3 compares the finite element results for the impact loading with the experimental results, and also compares the finite element results with the three hinged arch calculations. Finally, Chapter 4 presents recommendations regarding the impact loading used for design.

2 The Finite Element Model

Description of the Structure

As mentioned previously, the lower miter gate on the old Mississippi River Lock and Dam 26 was selected for this investigation as well as the experimental study. The lower miter was a vertically framed gate with each leaf approximately 45 feet high with 60 feet wide. The drawings for the gate are dated November 1933. Each leaf was made up of three panels with diagonals on both the upstream and downstream faces. The skin plate was made of buckled plates. The primary method of connection of the various structural elements of the gate was by riveting.

Overview of the Model Development Procedure

The first step in preparing the model was to obtain drawings of the gate. The original drawings had been preserved in storage and full size copies of the originals were obtained.

Based on reviewing the drawings and photographs, the model was developed. Although this gate was a vertically framed gate, the modelling approach used previously for horizontally framed gates (Ref. T.R. ITL-87-4, RPT. 1-7, AUG. 1987) was applicable. The major assumptions used in developing the model are listed below:

a. The gate would behave linearly elastically and undergo small deflections and rotations. This assumption was made in order to be able to perform a linear analysis on the gate. Photographs from the barge impact experimental studies clearly showed nonlinear behavior but this behavior appeared to be isolated to the impact area and was not considered to have a major effect on the overall structural behavior.

b. The riveted construction provided rigid connection of the various components of the gate just as would be assumed if modern welding techniques were used in the fabrication and erection of the gate.

c. The gate leafs were symmetrical.

d. The miter contact between the leafs was present for all loading conditions and there was no loss of contact.

e. The diagonals were tensioned so they would be immediately effective upon load application.

f. The webs of the vertical beams and the top and bottom horizontal girders were modelled using plate elements which could represent both in-plane and out-of-plane behavior. These elements assume that there is not any coupling of the in-plane and out-of-plane behavior at the element level. There is coupling in the overall model due to elements in different planes intersecting each other. The flanges of the vertical beam were modelled using one-dimensional space frame members. The properties of these flange members varied especially on the horizontal girders since the girder flanges had one to four cover plates at several locations. This assumes that the stress distribution across the flanges varies linearly.

g. The skin plate was also modelled using plate elements and the effect of the buckled plates was neglected. The elements were assumed to be flat.

h. The sill provided continuous support perpendicular to the flange of the bottom horizontal girder.

i. Stress concentrations due to the numerous rivets were ignored.

j. The dimensions shown on the drawings were assumed to be the same as in the actual structure. The model was based on the drawing dimensions.

k. Photographs of the gate revealed a box like area just below the top horizontal girder near midspan of the leaf. This area was not shown in the original drawings and may have been used to assist in the erection process. This area was modelled using plate elements and space frame members where appropriate. Properties for this box structure were assumed.

l. The pintle and gudgeon pin casting support points were approximated in the model. The detail required to accurately model these areas would have resulted in an unnecessarily fine mesh. The actual supports in these areas was assumed to be at single nodes in the model.

Description of the Model

The model was prepared using the GTSTRUDL program (GTICES Systems Laboratory, GTSTRUDL USERS MANUAL, Revision M, 1991, School of Civil Engineering, Georgia Tech, Atlanta). Space frame members and flat plate elements were utilized. The flat plate elements used in the model were SBHQ6 and SBHT6 elements. These elements can represent in-plane membrane behavior and out-of-plane bending behavior and also contain an artificial 6th degree-of-freedom to prevent numerical instabilities when modelling plate and shell structures.

Details regarding the modelling of various components of the model will be presented later. Figure 1 shows a wire frame view of the overall model. Figures 2 and 3 show upstream and downstream views of the model with hidden lines removed. The model contained 1,435 plate elements (SBHQ6 and SBHT6), 796 space frame members, and 1,435 nodes. A description of the modelling of the skin plate, diagonals, top and bottom girders, vertical girders and beams, and the quoin and miter regions is presented below.

Skin plate

The skin plate was modelled entirely with plate elements. The buckled plates were all modelled as flat elements. Horizontally, two divisions of elements were placed between each vertical beam and vertical girder. Each buckled plate was subdivided into two elements vertically. The thickness of all skin plate elements was 0.375 inches.

Diagonals and gusset plates

The diagonals were modelled as space frame members with hinges at each end. The cross section properties of each diagonal were computed based on a rectangular bar. Some of the bars were 8 inches wide and 1.25 inches thick, others 8 inches wide and 1 inch thick, and others 6 inches wide and 0.75 inches thick.

The gusset plates used to connect the diagonal bars to the rest of the structure were each modelled with two plate elements which were 1 inch thick.

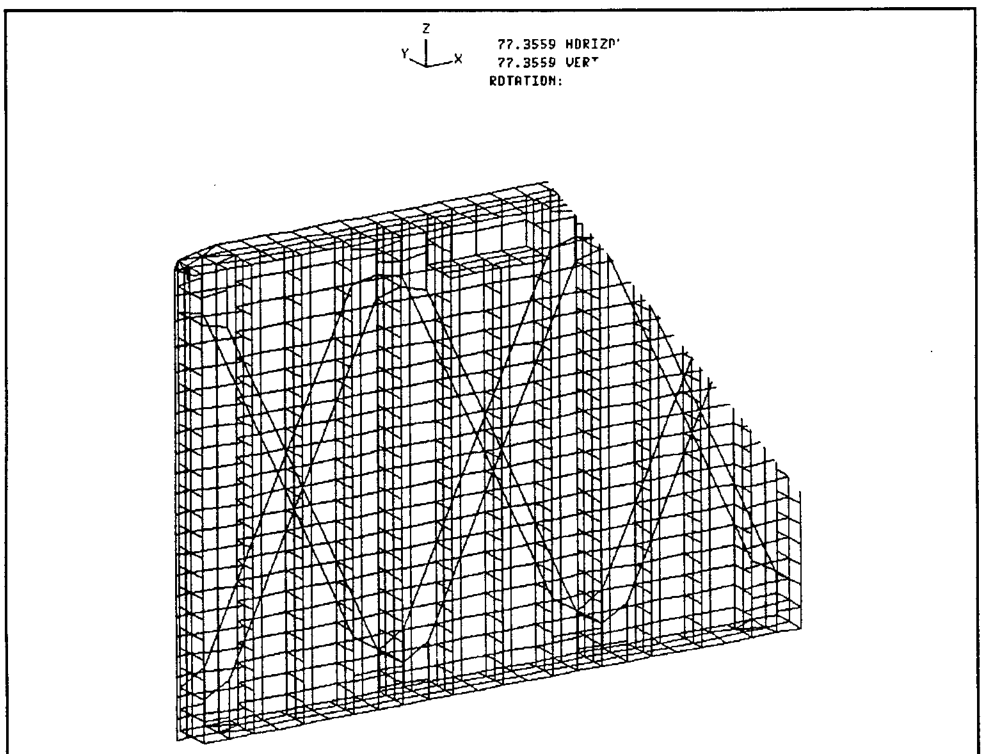

Figure 1. Wire frame view of leaf

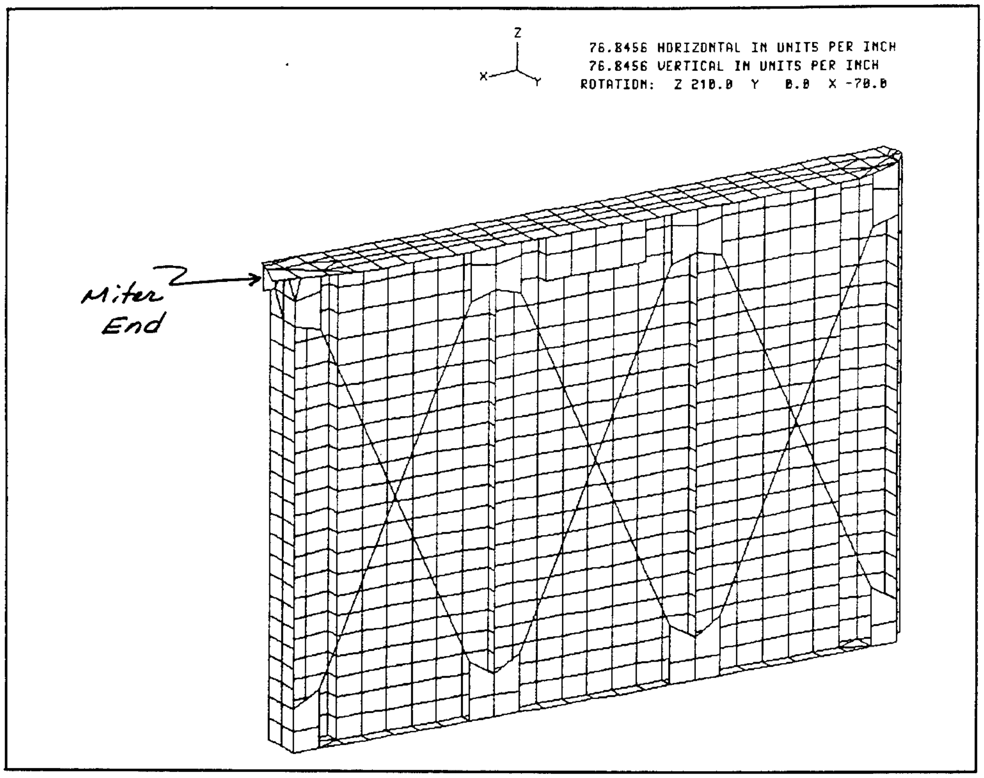

Figure 2. Upstream view of leaf with hidden lines removed

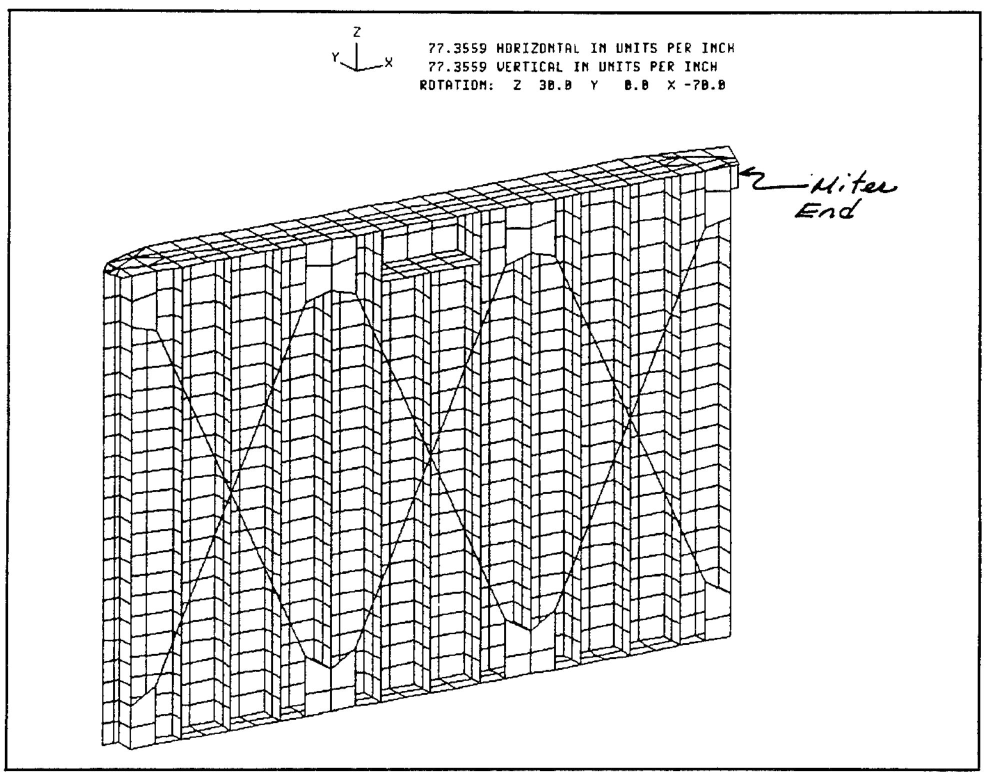

Figure 3. Downstream view of leaf with hidden lines removed

Top girder

The web of the top girder was modelled using plate elements which were 0.5 inches thick. The web was subdivided across its width with three elements. The subdivision along the length of the girder was the same as used for the skin plate. Figure 4 shows the mesh used to model the top girder utilizing the shrink option to shrink finite elements away from the edges. The shrink option was used so the elements and the space frame members could be seen.

As shown by Figure 4, space frame members were used to model the upstream and downstream flanges. The space frame members oriented horizontally between the upstream and downstream flanges represent angles used to connect the skin plate to the top girder. The properties for the downstream flange were calculated based on 2 angles, 8 inches x 6 inches x 0.875 inches thick with 0.5 inch spacing. The properties used to connect the skin plate were based on one angle, 3.5 inches x 3.5 inches x 0.375 inches.

The upstream flange properties were based on a double angle 8 inch x 8 inch x 0.875 inch with 0.5 inch spacing and with one to four 18 inch x 0.5 inch cover plates.

The quoin block flange casting properties were based on a 8 inch x 1 inch rectangular plate.

Bottom girder

The web of the bottom girder was modelled using plate elements which were 0.375 inches thick. As with the top girder, the web was subdivided across the girder depth with three elements. Figure 5 shows the mesh for the bottom girder.

Space frame members were used to model upstream and downstream flanges. The properties for the upstream flange were based on a single 6 inch x 6 inch x 0.5 inch angle. The downstream flange properties were based on double 6 inch x 3.5 inch x 0.5 inch angles with a 8 inch wide x 0.5 inch fill plate and a 8 inch x 0.5 inch bearing plate.

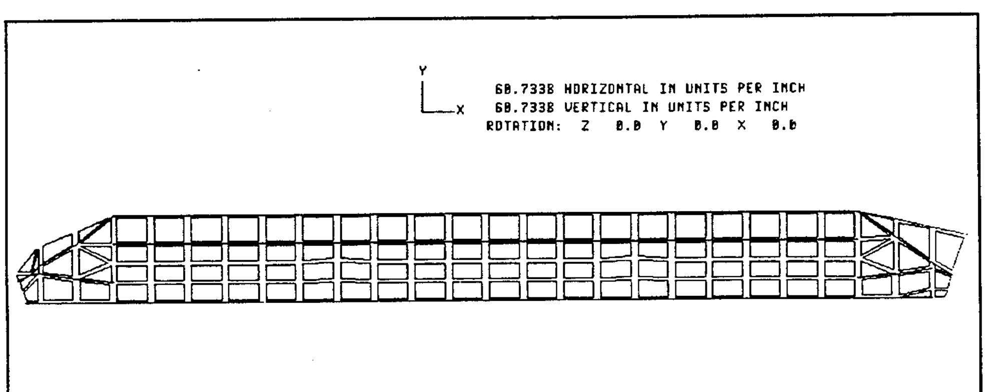

Figure 4. Top girder finite element shrink plot

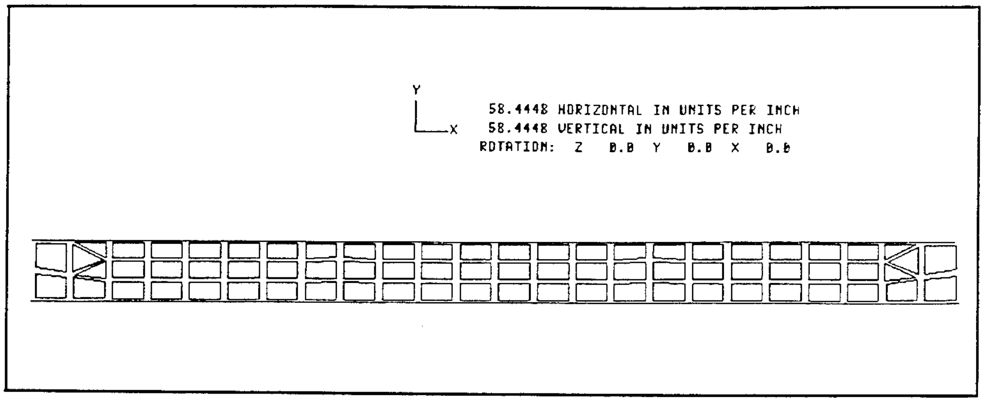

Figure 5. Bottom girder finite element shrink plot

Vertical girders

The web of the vertical girders was modelled with plate elements which were 0.375 inches thick. Three elements were used across the depth of these girders. The properties for the flanges of the vertical girders were calculated based on double 6 inch x 4 inch x 0.5 inch angles with 0.375 inch spacing. For the intermediate vertical girders, an additional vertical line of space frame members was used to model the angle used to connect the skin plate to the web of these intermediate girders. The properties of these members were calculated based on a double angles which were 3.5 inches x 3.5 inches x 0.375 inches with a 0.375 inch spacing. Figure 6 shows the mesh used to model the interior vertical girders.

Vertical beams

The web of the rolled vertical beams was modelled using plate elements which were 0.57 inches thick. Two elements were used across the depth of each vertical beam. The flanges of the vertical beam were modelled using space frame members. Figure 7 shows the mesh used to model each vertical beam.

The properties of the downstream flange were calculated based on a rectangular plate which was 11.5 inches wide by 0.805 inches thick. The properties of the upstream flange varied due to addition of splices and cover plates. All of the upstream flanges included an 11.5 inch wide by 0.805 inch thick flange. Some of the members also had upstream flanges with 12.5 inch x 0.375 inch splice plates while others had one to two 12.5 inch x 0.5 inch cover plates.

Vertical quoin beam

The rolled vertical beam in the quoin was also modelled using a combination of plate elements and space frame members for the flanges. The web was modelled with two plate elements across the depth which were 0.32 inches thick. The flange properties were calculated based on a rectangular plate which was 7.5 inches wide and 0.55 inches thick.

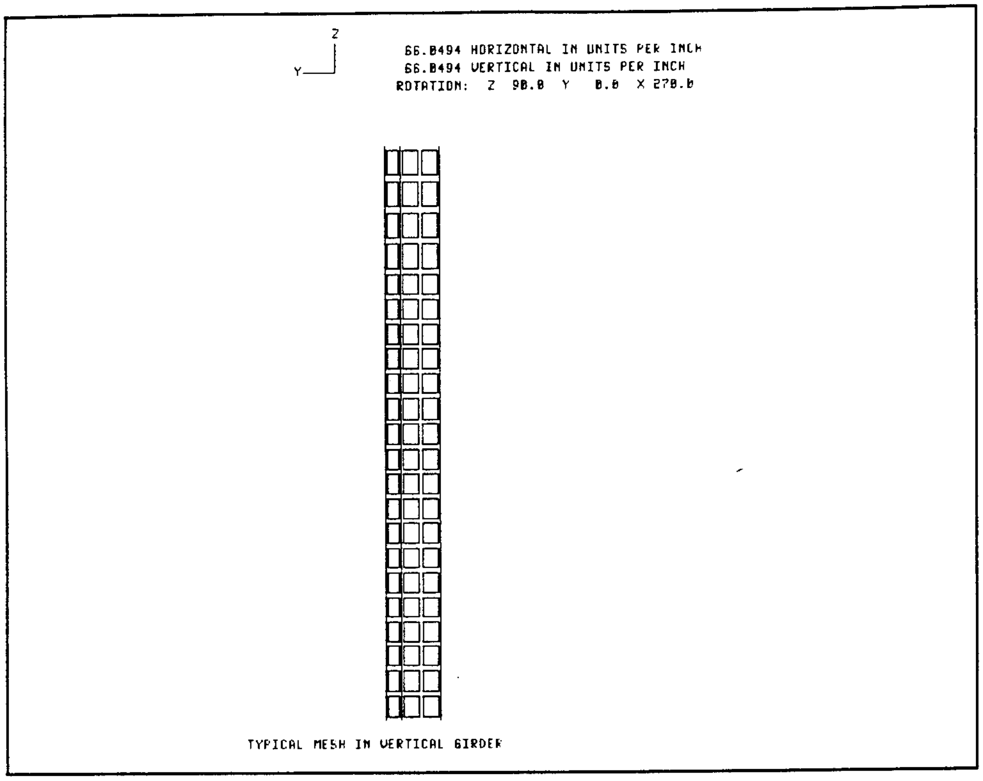

Figure 6. Interior vertical girder finite element shrink plot

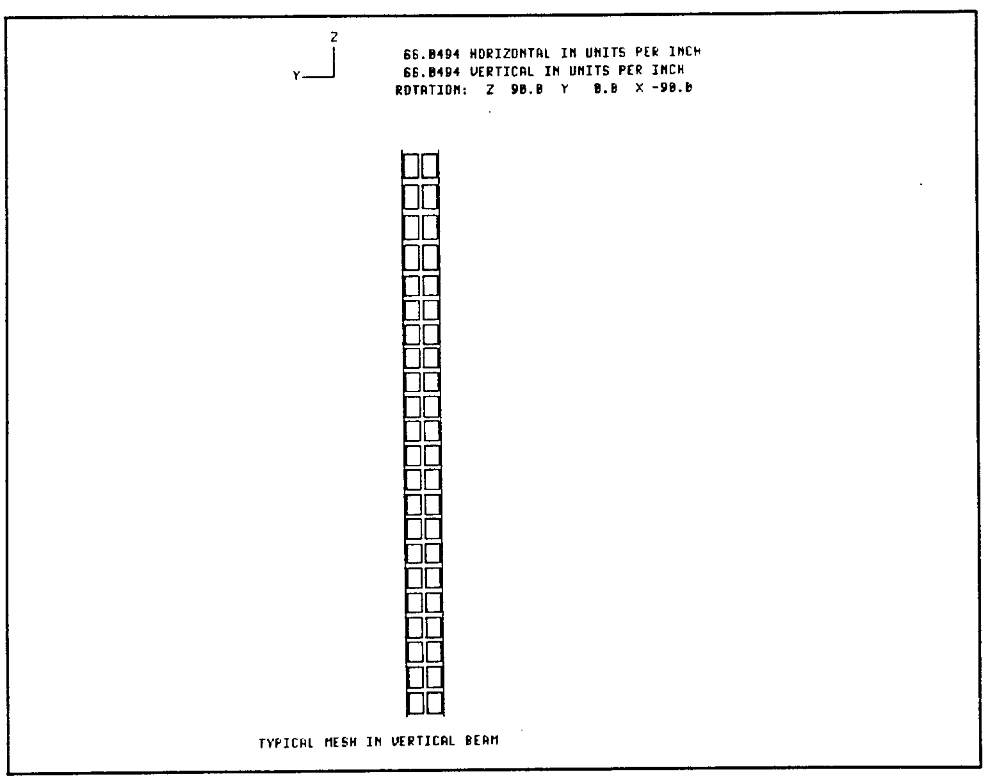

Figure 7. Typical vertical beam finite element shrink plot

Box below top girder near center of girder

As mentioned previously, the box structure below the top girder shown in Figures 1 to 3 was not indicated on the plans. Although this box could have been omitted from the model, it was represented since it was so close to the primary area of interest, the top girder. This box was modelled entirely using 0.5 inch thick plate elements.

Loading Conditions

The gate was assumed to be in the mitered position for all loading conditions. The loading conditions were developed to simulate the barge impact load of the experimental study and to consider EM 1110-2-2703 loadings for both horizontally and vertically framed gates. Loadings for both horizontally and vertically framed gates were considered in order to determine the suitability of these loadings. The loading conditions are briefly summarized below:

Loading 1 Impact load of 100 kips applied at the location of the barge impact in the experimental study. This load was transformed into global components and applied at the node in the model which was the closest to the barge impact location in the experimental study. Figure 8 shows the load components and location.

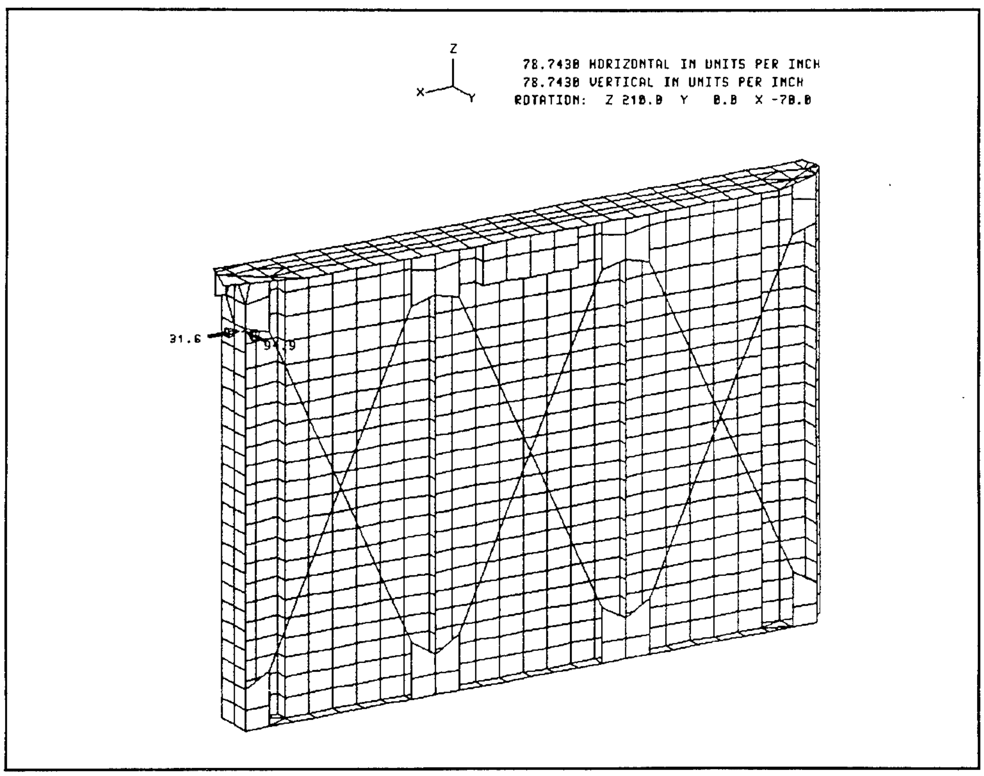

Figure 8. Components of 100 kip barge impact load - Loading 1

Loading 2 10 feet of head from 10 feet below the high pool to the top girder. This load was applied as a surface force normal to the skin plate elements and was used to simulate the loading for horizontally framed gates as specified by EM 1110-2-2703.

Loading 3 120 kip concentrated load applied at midspan of the top girder. This load is shown in Figure 9 and was used to represent the EM loading for vertically framed gates.

Loading 4 Hydrostatic load from 10 feet below high pool to bottom girder. This load was applied as a surface force normal to the skin plate elements in this region.

Loading 5 Hydrostatic load from high pool to 10 feet below high pool. This load was applied as a surface force normal to the skin plate elements in this region. Loadings 4 and 5 when added together represent the full hydrostatic loading.

Loading 6 Same as Loading 3. The boundary conditions for this loading were changed at the miter to antisymmetric boundary conditions. One half of this loading combined with one half of loading 3 represents a 120 kip barge impact on one leaf only. This load was used to represent the EM loading for vertically framed gates.

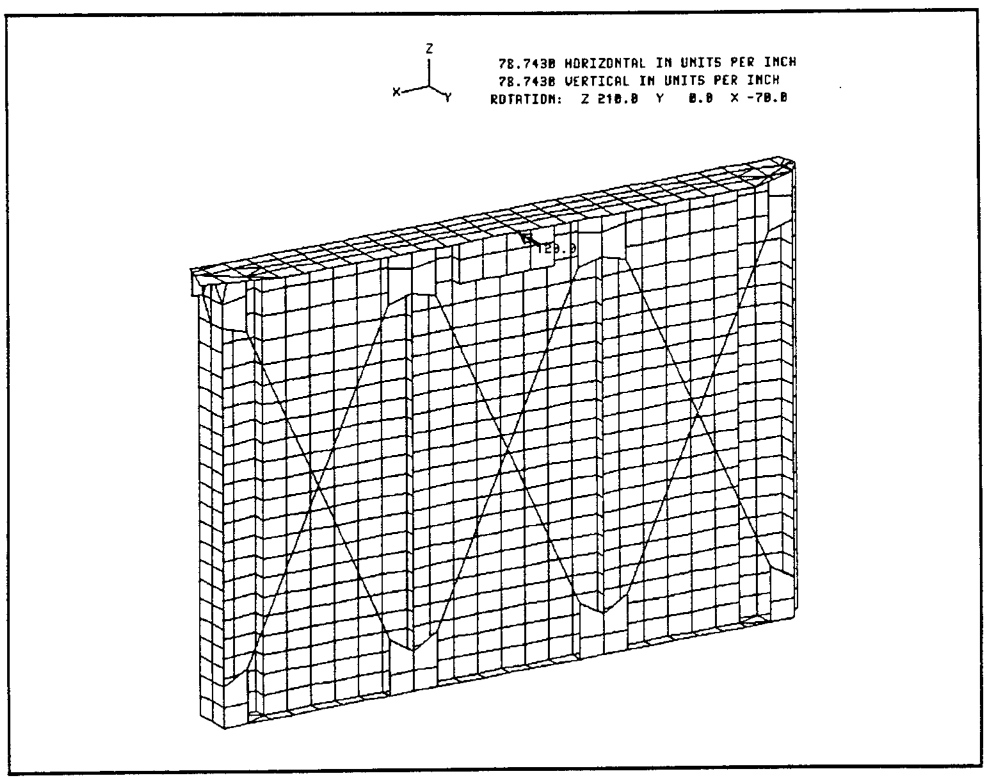

Figure 9. Concentrated load of 120 kips applied at center of top girder - Loading 3

Loading 7 This was a loading combination of loadings 2 + 4. This loading was used to simulate barge impact load (10 feet of head) plus hydrostatic head. This load was used to represent the EM loading for horizontally framed gates plus the hydrostatic head.

Loading 8 This was a loading combination of loadings 3 + 4 + 5. This loading was used to simulate barge impact on both leafs plus full hydrostatic head. This load was used to represent the EM loading for vertically framed gates plus hydrostatic head.

Loading 9 This was a loading combination of 0.5 x (loadings 3 + 6) + 4 + 5. This loading was used to simulate barge impact on one leaf only plus full hydrostatic head. These results are for the leaf modelled. This load was used to represent the EM loading for vertically framed gates plus hydrostatic head.

Loading 10 This was a loading combination of 0.5 x (loadings 3 - 6) + 4 + 5. This load was used to simulate barge impact on one leaf only plus full hydrostatic head. These results would represent those for the leaf which was not modelled. This load was used to represent the EM loading for vertically framed gates where only one leaf was impacted plus hydrostatic head.

Boundary Conditions

The gate was assumed to be in the mitered position for all loadings. Only two nodes existed along the miter since the miter seal was not modelled. For most loading conditions, symmetric boundary conditions were used along the miter. However, for the case of a barge impacting only one leaf, the loading was broken into symmetric and antisymmetric components since only one leaf was modelled which required the boundary conditions along the miter to be changed to antisymmetric for loading condition 6.

The symmetric boundary conditions at the miter were based on creating a local coordinate system at the two nodes by rotating -18.43 degrees about the global Z direction. This created a local X direction in the direction of the miter block. The only restraint for the symmetric boundary conditions was in this local X direction. The antisymmetric boundary conditions at the miter also used this local coordinate system. The only restraints at the miter for the antisymmetric case were in the local Y direction and in the local Z direction which was the same as the global Z direction.

Along the bottom girder, the gate was assumed to be in contact with the sill along its entire length. The nodes along the downstream flange of the bottom girder were restrained only against movement normal to the girder.

The restraint by the quoin block on the top girder was represented with one node which was restrained in the direction of the quoin block but was free to translate in other directions and rotate freely.

The support at the pintle was modelled with one node on the bottom girder. This node was restrained against all translation but was allowed to rotate freely.

The support at the gudgeon pin was modelled with one node on the top girder. This node was restrained against translation in the plane of the web of the top girder but was free to move vertically and to rotate.

Figure 10 shows the full model of the gate leaf with the restrained supported nodes labelled.

GTSTRUDL Input File

A listing of the GTSTRUDL input used in the analysis is included in Appendix A. This listing is commented to aid in the understanding of the modelling procedure.

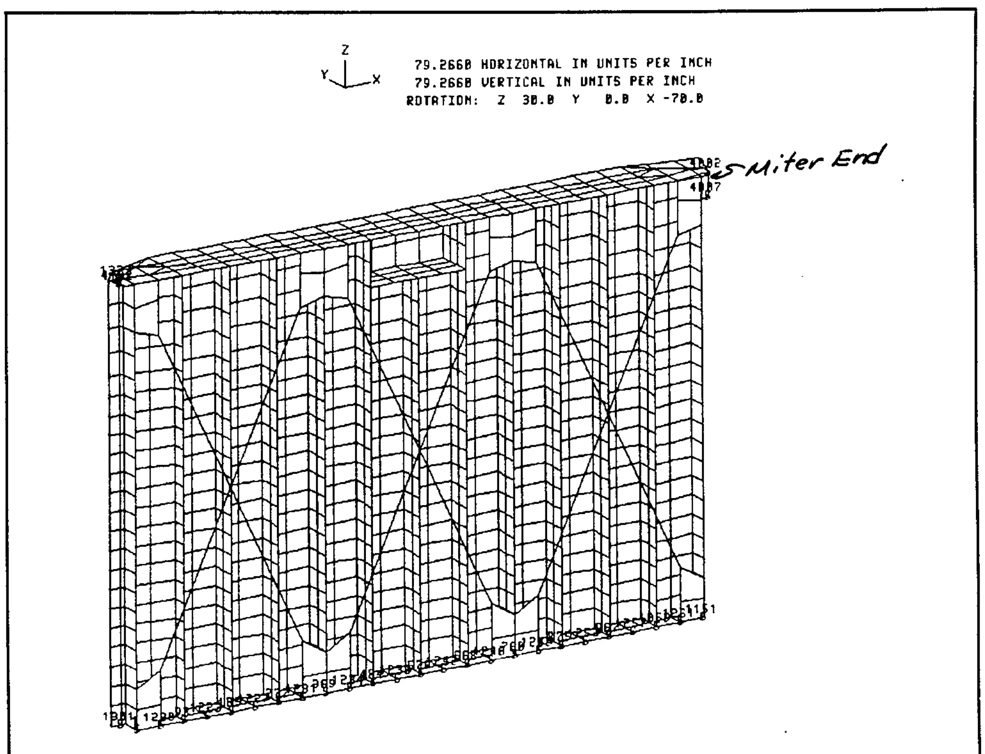

Figure 10. Support locations

3 Analytical and Experimental Results

Analysis Procedure and Results

Once the model was generated, a linear static analysis was run for independent Loadings 1 to 5 for symmetric boundary conditions at the miter. The boundary conditions were then changed to be antisymmetric at the miter and a second linear analysis was run for Loading 6 only. After this analysis had been completed, Loading Combinations 7 to 10 were formed. Selected results were then output and graphical displays of the deformed shape and stress contours in the top girder were obtained. The analysis sequence, changes in boundary conditions, and creation of the loading combinations are given in the input listing in Appendix A.

Experimental and Analytical Results for Loading 1

A stress contour plot of the SXX stress component in the top girder due to Loading 1 is shown in Figure 11. The contour lines on the contour plot are labelled with integers such as -2, -1, and 0. The stress associated with the contour line is determined by multiplying the integer on the line by the Contour Step Value which is found to the left of the X-Y coordinate axes. For the contour plot in Figure 11, the Contour Step Value is 2.0 ksi. Therefore, the SXX stress on a contour line labelled with a -2 is -4.0 ksi with the negative sign indicating compression. The SXX stress component is the normal stress component in the

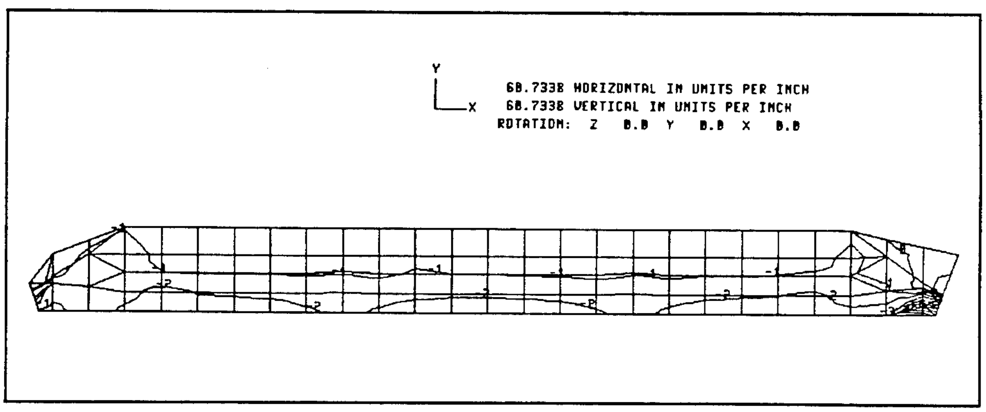

Figure 11. SXX stress contour in top girder for Loading 1

X-direction of the planar coordinate system in GTSTRUDL. For the top girder, the planar X direction is the same as global X which corresponds to the longitudinal direction of the miter leaf. As shown by Figure 11, the stress variation was high near the quoin and miter ends of the top girder with the greatest variation near the miter end. This is due to the 100 kip load being applied just below the top girder near the miter end and the supports being modelled at points rather than being distributed as they are in the real structure.

Stresses obtained from the finite element analysis of the model were then compared with stresses calculated from strain gage readings on the top girder. Experimental results existed for a total barge impact of 203 kips which was very close to the 200 kip total applied load in Loading 1 (100 kips applied to each leaf of the gate). The SXX stresses at the nodes which were the closest to the strain gage locations in the upstream and downstream flanges of the top girder were used for the comparison. The location of these nodes is shown in Figure 12. A comparison of the results is shown in Table 1 below.

The results indicate that the finite element model is predicting the compressive stress on the downstream flange of the top girder within 11 percent of the experimental results. On the upstream flange, the percentage difference is much larger due to the smaller magnitude of the stresses. The largest difference

Table 1
Finite Element and Experimental Stresses

Strain gage, location (Chasten, 1991)	Stress based on strain gage readings (ksi)	Finite element node	Finite element nodal stress (ksi)
I	-0.11	2267	-0.79
N	-4.34	251	-4.83
G	0.04	2275	-0.54
H	-5.08	642	-4.67
AF	0.04	2283	-0.83
U	-4.89	1033	-4.87

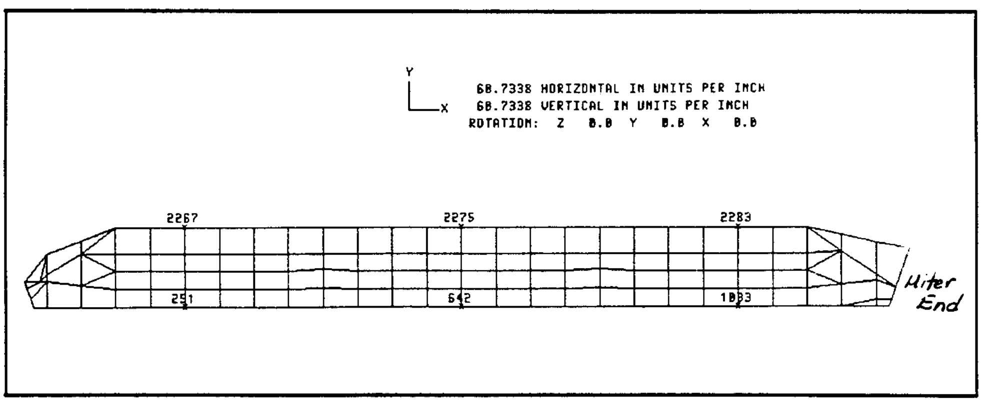

Figure 12. Location of nodes used for comparison with experimental results for Loading 1

in stress in the upstream flange is -0.79 ksi. The finite element model is consistently predicting more compression in the upstream flange. Despite this variation, the results compare well and the model calibration was not necessary for other loadings.

Stress Results for Other Loadings

Finite element SXX stress contour plots for the top girder were also obtained for Loadings 2, 3, and 7 to 10. Contour plots were not obtained for Loadings 4, 5, and 6 since these are realistic only when combined with other loadings. The contour plots for Loadings 2, 3, and 7 to 10 are shown in Figures 13-18, respectively.

As stated in Chapter 2, the motivation for using other loadings was to determine the suitability of these loadings. Loading 2 represents the barge impact loading for horizontally framed gates. Loading 3 was used to model a barge impact of 120 kips at midspan of the top girder to represent guidance for barge impact on vertically framed gates. Comparing the contour plots for Loadings 2 and 3 shown in Figures 13 and 14 respectively, clearly indicates major differences in the behavior of the gate leaf. The stress magnitude and

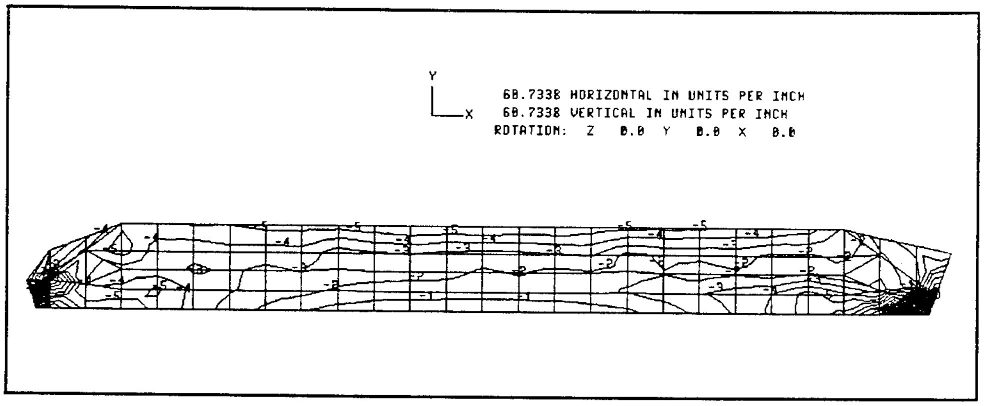

Figure 13. SXX stress contour in top girder for Loading 2

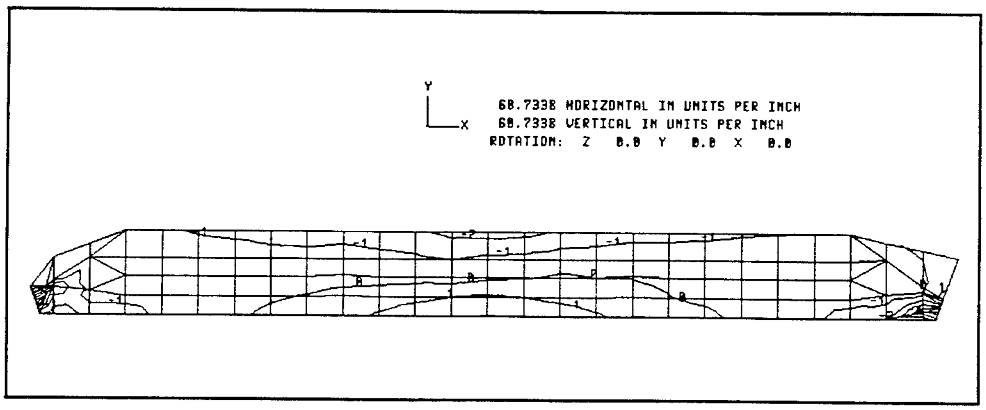

Figure 14. SXX stress contour in top girder for Loading 3

distribution are very different in the top girder for these two loadings. Using the contour lines to obtain the stress magnitude for the upstream and downstream flanges at midspan yields stresses of approximately -10 and 0 ksi for Loading 2 and approximately -4 and 4 ksi for Loading 3. Similarly when Loadings 2 and 3 are combined with full hydrostatic head to form Loadings 7 and 8, the results are very different as shown in the contour plots in Figures 15 and 16. The results for the upstream and downstream flanges at midspan are approximately -16 and 0 ksi respectively for Loading 7 and approximately -12 and 4 ksi respectively for Loading 8.

Loadings 9 and 10 were used to determine the effect on the model of a barge impacting only one leaf of the gate plus full hydrostatic head. A concentrated load of 120 kips was applied at midspan of the top girder on one leaf only. Since only one leaf was modelled, Loading 9 was used to represent the behavior of the leaf which the barge impacted while Loading 10 was used to represent the behavior of the leaf which was not impacted. The stress contours for Loadings 9 and 10 are shown in Figures 17 and 18 respectively. The leaf with the barge impact (Figure 17) exhibits higher stresses and stress gradients than the leaf which was not impacted (Figure 18) as expected.

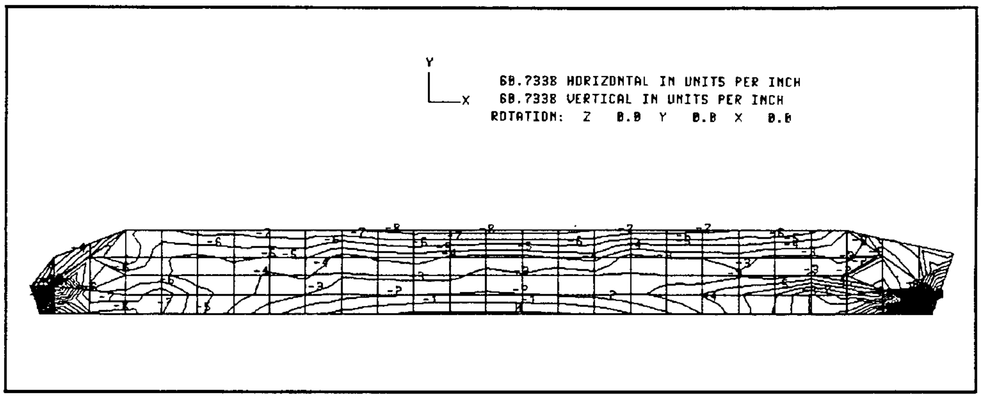

Figure 15. SXX stress contour in top girder for Loading 7

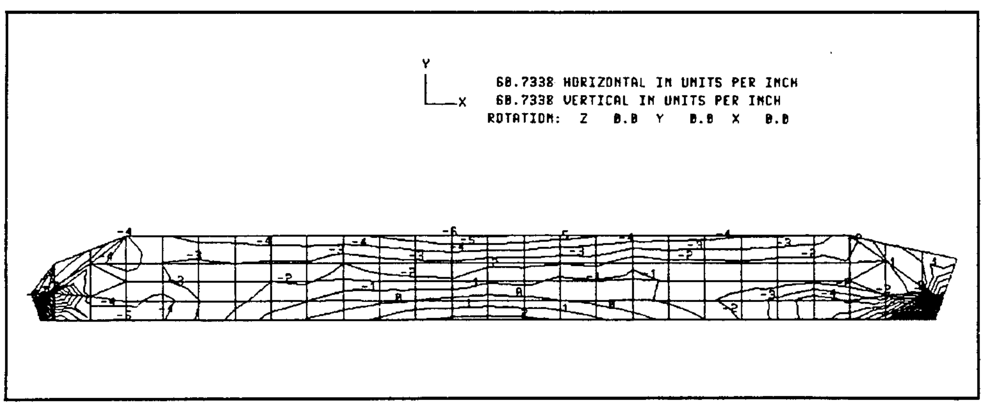

Figure 16. SXX stress contour in top girder for Loading 8

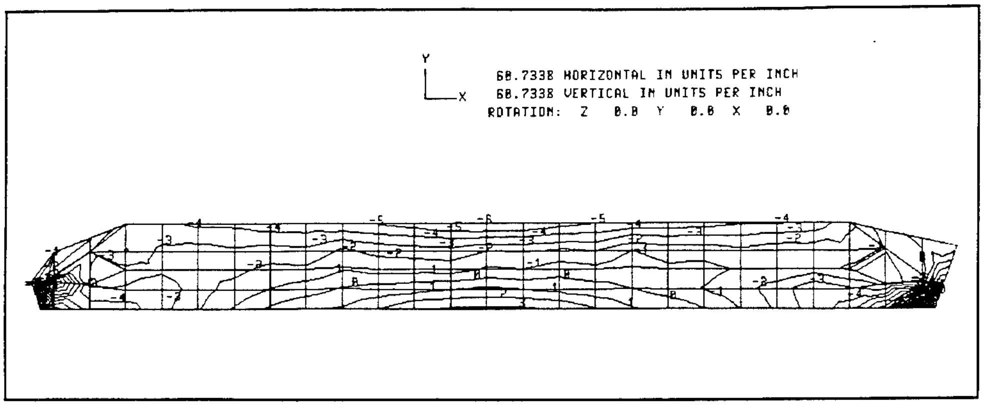

Figure 17. SXX stress contour in top girder for Loading 9

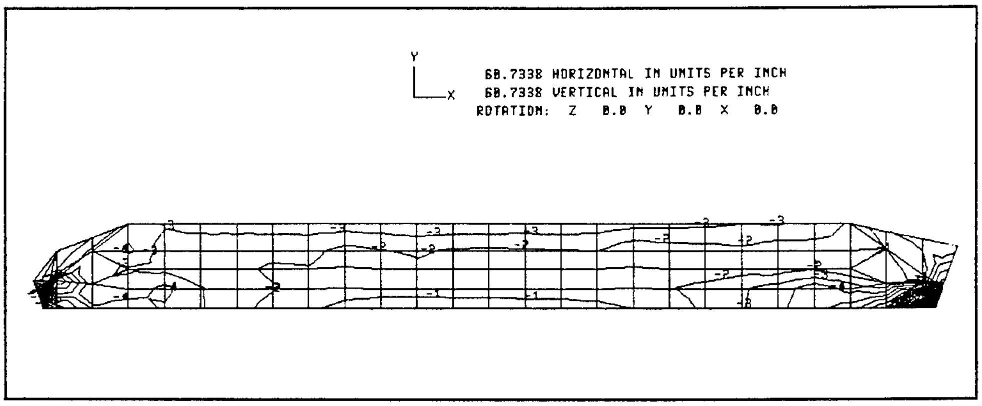

Figure 18. SXX stress contour in top girder for Loading 10

Comparing the results with only one leaf impacted plus full hydrostatic as shown in Figure 17 with the results from both leafs impacted plus full hydrostatic as shown in Figure 16 indicates that the stresses are not affected as much as might be expected. For instance, the stress magnitude obtained using the contour lines for the upstream and downstream flanges at midspan are approximately -12 and 4 ksi respectively for Loading 8 and approximately -12 and 6 ksi respectively for Loading 9. The distribution of the stresses is also very similar.

Three hinged arch hand computations were also performed for all of the loadings. The purpose of this analysis was to determine if the finite element results were reasonable. For Loadings 2, 4, and 5 which were distributed hydrostatic loads applied below the top girder, a vertical unit width of the gate was taken that was assumed to be simply supported between the top and bottom girders. The top girder reaction was then used as a distributed load applied normal to the three hinged arch members. For Loading 1 which was the 100 kip barge impact loading applied below the top girder, the hydrostatic load was assumed to be distributed between the top and bottom girders assuming the miter girder acted as a simply supported beam between the top and bottom girders. This resulted in 89.0 kips being applied to the top girder on each leaf directly above the impact point.

Once the forces acting on the three hinged arch were determined, the reactions were computed and the axial and shear forces at the quoin were computed. Stresses in the upstream and downstream flanges of the top girder at midspan were computed assuming the girder acted as a beam-column using P/A plus or minus Mc/I where P is the axial load, A is the cross section area, M is the bending moment, c is the distance in the plane of the cross section from the centroid to the location of stress computation, and I is the moment of inertia of the cross section. In computing M, the eccentricity of the line of action of the axial load and the centroid of the beam at midspan was taken into account. The results of these calculations and a comparison with the finite element results are shown in Table 2 below.

Table 2
Finite Element and Three-Hinge Arch Stresses

Loading	Three hinged arch stress (ksi)		Finite element stress (ksi)	
	Upstream	Downstream	Upstream	Downstream
1	0.89	-7.86	-0.54	-4.67
2	-10.7	0.30	-11.97	-0.19
3	-4.70	5.15	-4.72	4.07
4	-7.00	0.16	-5.44	0.57
5	-1.92	0.04	-2.17	0.02
7	-17.7	0.46	-17.42	0.38
8	-13.6	5.35	-12.33	4.67
9	-13.9	8.10	-12.83	6.44
10	-8.60	-2.60	-8.08	-0.54

The results in the above table indicate that the finite element results appear reasonable. In fact, for some loadings, the results agree surprisingly well given the number of approximations involved in the three hinged arch calculations. For Loadings 1, 3, 4, 7, 8, 9, and 10, the three hinged arch results are conservative considering the stresses with the largest magnitude. In Loading 2, the three hinged arch results were within 12 percent of the upstream flange compressive stress in the finite element model.

Even though the three hinged arch results for Loading 1 are conservative, the difference in the results for Loading 1 is cause for some concern since the finite element results compared favorably with the experimental results for this case. After examination of the hand calculation results and assumptions, no single major cause of these differences could be determined. One factor which could have contributed to the difference for Loading 1 are the assumption of a constant eccentricity of 3.75 feet in the hand calculations. The load in Loading 1 was applied as a concentrated load with global X and Y components of -31.62 and -94.87 kips respectively. The application point of these components is shown in

Figure 9. As can be seen from this Figure, the X component of -31.62 is applied at a point away from the line joining the miter and quoin end supports by a considerable distance. This causes a change in the effective eccentricity. The hand calculations assumed the load was applied parallel to the lock wall and on the line joining the miter and quoin points of support. Furthermore, the gudgeon pin location in the finite element model was also restrained in the X and Y directions. This also produces a shift in the eccentricity. Another factor which may have contributed to the difference between the hand calculation and finite element results is the box structure located below the top girder near midspan. The box was ignored in the hand calculations but present in the finite element model and in the experimental study.

Deformed Shape of the Structure for Loadings 1, 2, and 3

Deformed shape plots of the top girder were made for Loadings 1, 2, and 3. The deformed shape of the top girder is shown by dashed lines in Figures 19, 20, and 21 for Loadings 1, 2, and 3 respectively. The undeformed shape of the top girder is shown by solid lines in these figures. The magnitude of the deformations was amplified in order to be seen. The maximum negative Y component of the displacement was -0.37 inches for Loading 1, -0.22 inches for Loading 2, and -0.78 inches for Loading 3.

The differences in the deformed shapes are clearly evident from Figures 19-21. The deformed shape of the top girder for Loading 2 and Loading 3 are similar but not the same. Comparing the deformed shapes of Loadings 1 and 2 indicates very dissimilar shapes. Clearly, the 10 feet of hydrostatic head from 10 feet below the top girder to the top girder does not accurately represent the effect of a barge impact on a vertically framed miter gate.

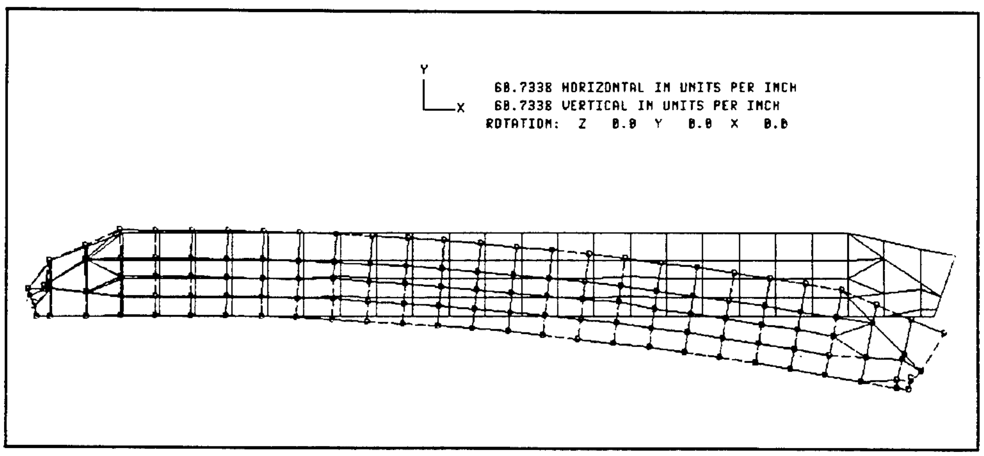

Figure 19. Original and deformed shape of top girder for Loading 1

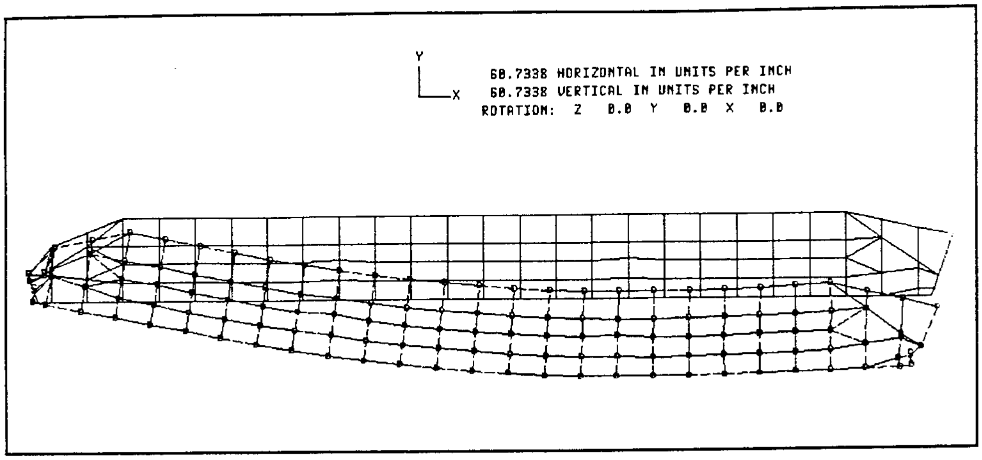

Figure 20. Original and deformed shape of top girder for Loading 2

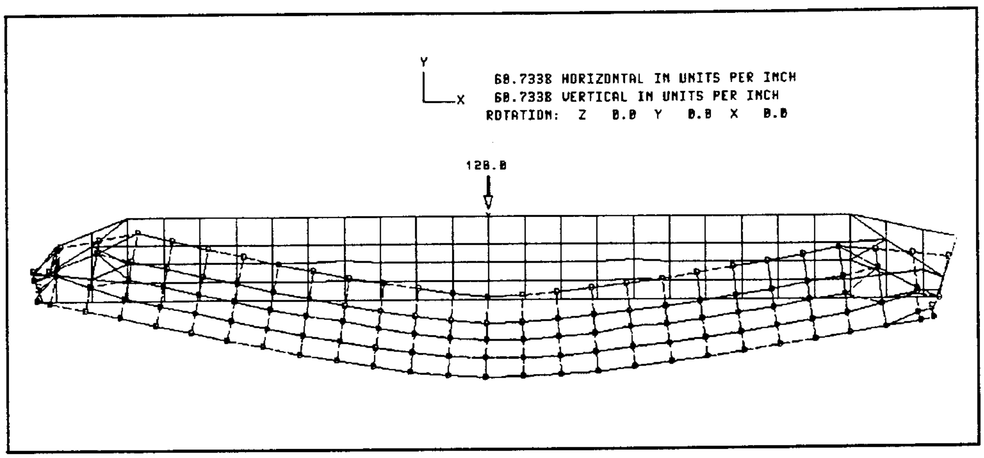

Figure 21. Original and deformed shape of top girder for Loading 3

4 Recommendations

This study indicates that a finite element model can be developed which accurately represents an experimental barge impact study for a closed vertically framed miter gate. However, design engineers will not develop finite element models but more likely use a three hinged arch approximation as also done in this study. The three hinged arch computations performed in this study were performed mainly to establish if the finite element results were reasonable. The stresses predicted by the three hinged arch at the midspan of the top girder were surprisingly close to the finite element results for many of the loadings in this study and were usually conservative. The point of application of the barge impact should be considered when calculating the moment at the centroid of a section along the length when using the three hinge arch load assumptions.

Based on the deformed shape plots in Chapter 3, the use of hydrostatic head to represent barge impact is not reasonable for vertically framed gates. It is also hard to justify the use of hydrostatic head for horizontally framed gates since each girder in a horizontally framed gate should deform similar to the top girder of a vertically framed gate. The hydrostatic head approach can not accurately represent barge impacts which could occur almost anywhere along the length of the gate. The Corps of Engineers has been using the hydrostatic head criteria for many years so it must be conservative because barge impacts have occurred.

A more reasonable impact loading appears to be a concentrated load that can be applied anywhere along the length of a girder. The difficulty is establishing the magnitude of the concentrated load and for horizontally framed gates, also establishing the distribution of the load to neighboring horizontal girders. Both the magnitude and distribution of the impact load depend on the stiffness of the various components of the gate. One technique to determine the magnitude of the impact loads would be to instrument gates in service. The distribution of the load to surrounding horizontal girders could also be determined in the experimental study. Such a study might not be financially feasible or practical in the actual operation of the gate.

The new EM 1110-2-2105, Design of Hydraulic Steel Structures, 1993, established the magnitude of the concentrated impact load so as to produce a design similar to previous designs which used the hydrostatic head criteria. This appears to be a conservative approach. The distribution of the impact load to neighboring horizontal girders could be determined using existing finite element models and applying concentrated loads to represent the impact. The reactions at

the quoin and miter blocks could be used to establish the distribution of the load to the horizontal girders.

Appendix A
GTSTRUDL Input File

```
*TITLE 'ANALYSIS OF 44 FT 7 IN HIGH MITER GATE'
STRUDL 'MITER45' 'ANALYSIS OF 45 FT HIGH MITER GATE , JULY 1991'
$
$
TYPE SPACE FRAME
$
MATERIAL STEEL
$
UNITS INCHES KIPS
$
$ ------------------------------------------------------------------------
$
$ JOINTS IN QUOIN AND MITER GIRDERS
$
$ ------------------------------------------------------------------------
$
PRINT GENERATE OFF
$
GENE 3 JOI ID 1 1 X 0 0 Y 0 24.125
REPEAT 22 TIMES ID 3 Z DIFF 2 AT 24.25, 14 AT 23., 2 AT 23.625, 4 AT 29.3125
REPEAT 1 TIME ID 1150 X 696.
$
$ ------------------------------------------------------------------------
$
$ JOINTS IN VERTICAL BEAMS
$
$ ------------------------------------------------------------------------
$
$   BEAMS 1 -3
$
GENE 3 JOI ID 93 1 X 58 Y 0 16.5
REPEAT 22 TIMES ID 3 Z DIFF 2 AT 24.25, 14 AT 23., 2 AT 23.625, 4 AT 29.3125
REPEAT 2 TIMES ID 92 X 58
$
$   BEAMS 4-6
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GENE 3 JOI ID 484 1 X 290 Y 0 16.5
REPEAT 22 TIMES ID 3 Z DIFF 2 AT 24.25, 14 AT 23., 2 AT 23.625, 4 AT 29.3125
REPEAT 2 TIMES ID 92 X 58
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$   BEAMS 7-9
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GENE 3 JOI ID 875 1 X 522 Y 0 16.5
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REPEAT 2 TIMES ID 92 X 58
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$ ------------------------------------------------------------------------
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GENE 4 JOI ID 369 1 X 232 Y DIFF 0 2 AT 17.4375 13.375
REPEAT 22 TIMES ID 4 Z DIFF 2 AT 24.25, 14 AT 23., 2 AT 23.625, 4 AT 29.3125
REPEAT 1 TIMES ID 391 X 232
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$  INTERMEDIATE JOINTS IN SKIN PLATE BETWEEN GIRDERS AND BEAMS
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          4 AT 29.3129
REPEAT 1 ID 1058 X 638
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GENE 23 JOI ID 162 1 X 87. Y 33. Z DIFF 0. 2 AT 24.25, 14 AT 23., 2 AT 23.625, -
          4 AT 29.3129
REPEAT 2 TIMES ID 92 X 58.
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GENE 23 JOI ID 461 1 X 261 Y 33. Z DIFF 0. 2 AT 24.25, 14 AT 23., 2 AT 23.625, -
          4 AT 29.3129
REPEAT 3 TIMES ID 92  X 58.
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GENE 23 JOI ID 852 1 X 493 Y 33. Z DIFF 0. 2 AT 24.25, 14 AT 23., 2 AT 23.625, -
          4 AT 29.3129
REPEAT 2 TIMES ID 92 X 58.
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1 AT 348, 3 AT 377, 406, 3 AT 435, 3 AT 493, 522, 3 AT 551, 1 AT 580, 3 AT 609 -
638, 2 AT 667, Y LIST -
0, 48.25,48.25,0,16.5,48.25,48.25,0,16.5,48.25,48.25,0,16.5,48.25,0,16.5, -
2 AT 48.25, 0,16.5, 2 at 48.25,0,16.5,2 at 48.25,0,16.5,48.25,0,16.5, -
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GENE 23 JOI ID 1301 1 X -6 0 Y 24.125 0 Z DIFF 0., 2 AT 24.25, -
              14 AT 23., 2 AT 23.625, 4 AT 29.3129
REPEAT 1 ID 23 X -12.
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$  ADDITIONAL JOINTS NEEDED FOR TOP GIRDER WHICH IS 6 FT WIDE
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GENE 25 JOI ID 2263 1 X 0 29. Y 72. Z 535
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$  ADDITIONAL JOINTS NEEDED FOR GUSSET PLATES FOR DIAGONALS
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3003 203.  0.  24.25
3004 203.  0.  66.875
3005 261   0.  24.25
3006 261.  0.  66.875
$
3007 435.  0.  24.25
3008 435.  0.  66.875
3009 493.  0.  24.25
3010 493.  0.  66.875
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3011 667.  0.  24.25
3012 667.  0.  66.875
$
3013  29.  0. 468.125
3014  29.  0. 511.
$
3015 203.  0. 468.125
3016 203.  0. 511.
3017 261.  0. 468.125
3018 261.  0. 511.
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REPEAT 21 ID 2 F 3
REPEAT 1 ID 44 F 1150
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GENE 2 ELEM ID 89 1 F 94 1 T 93 T 96 T 97
REPEAT 21 ID 2 F 3
REPEAT 2 ID 44 F 92
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GENE 2 ELEM ID 221 1 F 485 1 T 484 T 487 T 488
REPEAT 21 ID 2 F 3
REPEAT 2 ID 44 F 92
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GENE 2 ELEM ID 353 1 F 876 1 T 875 T 878 T 879
REPEAT 21 ID 2 F 3
REPEAT 2 ID 44 F 92
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$
$  GENERATE ELEMENTS IN SKIN PLATE
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$ ---------------------------------------------------------------------------
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GENE 22 ELEM ID 500 24 F 2 3 T 70 1 T 71 1 T 5 3
$
GENE 22 ELEM ID 501 24 F 70 1 T 94 3 T 97 3 T 71 1
$
GENE 22 ELEM ID 502 24 F 95 3 T 162 1 T 163 1 T 98 3
REPEAT 2 ID 2 F 92
REPEAT 2 ID 8 F 391
$
GENE 22 ELEM ID 503 24 F 162 1 T 187 3 T 190 3 T 163 1
REPEAT 1 ID 2 F 92
REPEAT 2 ID 8 F 391
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GENE 22 ELEM ID 507 24 F 346 1 T 371 4 T 375 4 T 347 1
REPEAT 1 ID 8 F 391
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GENE 22 ELEM ID 508 24 F 371 4 T 461 1 T 462 1 T 375 4
REPEAT 1 ID 8 F 391
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REPEAT 1 ID 8 F 391
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CHANGES
GENE 22 ELEM ID 522 24 F 1060 3 T 1128 1 T 1129 1 T 1063 3
ADDITIONS
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1102 2 70 1221 3
1103 1220 93 94 70
1107 93 1223 1224 94
1108 94 1224 162 95
1109 95 162 1225 1222
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1111 1224 186 187 162
1112 162 187 1226 1225
1113 185 1227 1228 186
1114 186 1228 254 187
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1121 279 346 1233 1230
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1123 1232 370 371 346
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1125 369 1234 1235 370
1126 370 1235 461 371
1127 371 461 1236 372
1128 1234 484 485 1235
1129 1235 485 486 461
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1143 668 1246 1247 669
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$  ELEMENTS IN INTERMEDIATE VERTICAL GIRDERS
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REPEAT 21 TIMES ID 3 F 4
REPEAT 1 TIME ID 66 F 391
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3102 68 92 2221 69
3103 2220 159 160 92
3107 159 2223 2224 160
3108 160 2224 184 161
3109 161 184 2225 2222
3110 2223 251 252 2224
3111 2224 252 253 184
3112 184 253 2226 2225
3113 251 2227 2228 252
3114 252 2228 276 253
3115 253 276 2229 2226
3116 2227 343 344 2228
3117 2228 344 345 276
3118 276 345 2230 2229
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3119 343 2231 2232 344
3120 344 2232 368 345
3121 345 368 2233 2230
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3123 2232 458 459 368
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3125 457 2234 2235 458
3126 458 2235 483 459
3127 459 483 2236 460
3128 2234 550 551 2235
3129 2235 551 552 483
3130 483 552 2237 2236
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3105 92 161 2221
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3168 1126 1150 1127
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3170 1127 2262 2260
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3176 2225 2226 2267 2266
3177 2226 2229 2268 2267
3178 2229 2230 2269 2268
3179 2230 2233 2270 2269
3180 2233 460 2271 2270
3181 460 2236 2272 2271
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3183 2237 2240 2274 2273
3184 2240 2241 2275 2274
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3186 2244 2245 2277 2276
3187 2245 2248 2278 2277
3188 2248 851 2279 2278
3189 851 2251 2280 2279
3190 2251 2252 2281 2280
3191 2252 2255 2282 2281
3192 2255 2256 2283 2282
3193 2256 2259 2284 2283
3194 2259 2260 2285 2284
3195 2260 2262 2286 2285
3196 2262 1219 2287 2286
$
$ ----------------------------------------------------------------------
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$  MEMBERS USED FOR FLANGES
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$ ----------------------------------------------------------------------
$
$  FLANGES FOR QUOIN AND MITER GIRDERS
$
$ ----------------------------------------------------------------------
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$
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REPEAT 1 ID 22 F -2
REPEAT 1 ID 44 F 1150
$
$  FLANGES FOR INTERMEDIATE VERTICAL GIRDERS
$
GENE 22 MEM ID 2089 1 F 372 4 T 376
REPEAT 1 ID 22 F -3
REPEAT 1 ID 44 F 391
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$
$ ----------------------------------------------------------------------
$
$  FLANGES FOR VERTICAL BEAMS
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$ ----------------------------------------------------------------------
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GENE 22 MEM ID 2177 1 F 95 3 T 98
REPEAT 1 ID 22 F -2
REPEAT 2 ID 44 F 92
$
GENE 22 MEM ID 2309 1 F 486 3 T 489
REPEAT 1 ID 22 F -2
REPEAT 2 ID 44 F 92
$
GENE 22 MEM ID 2441 1 F 877 3 T 880
REPEAT 1 ID 22 F -2
REPEAT 2 ID 44 F 92
$
$ ----------------------------------------------------------------------
$
$  FLANGES FOR VERTICAL I BEAM FROM QUOIN TO PINTLE
$
$ ----------------------------------------------------------------------
$
```

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GENE 22 MEM ID 2601 1 F 2 3 T 5 3
GENE 22 MEM ID 2623 1 F 1324 1 T 1325 1
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$
$  MEMBERS USED TO CONNECT SKIN PLATE TO INTERMEDIATE VERTICAL GIRDERS
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$ ======================================================================
$
GENE 22 MEM ID 2701 1 F 371 4 T 375 4
REPEAT 1 ID 22 F 391
$
$ ======================================================================
$
$  FLANGES FOR BOTTOM GIRDER
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2803 93 1223
2804 1223 185
2805 185 1227
2806 1227 277
2807 277 1231
2808 1231 369
2809 369 1234
2810 1234 484
2811 484 1238
2812 1238 576
2813 576 1242
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2824 1261 1151
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GENE 24 MEM LIST
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2827 1222 1225
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2844 1255 1256
2845 1256 1259
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2847 1260 1262
2848 1262 1153
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$ ======================================================================
$
$  FLANGES FOR TOP GIRDER AND INTERMEDIATE CONNECTION FOR SKIN PLATE
$
$ ======================================================================
$
MEM INC
3801 67 2220
3802 2220 159
3803 159 2223
3804 2223 251
3805 251 2227
3806 2227 343
```

```
3807 343 2231
3808 2231 457
3809 457 2234
3810 2234 550
3811 550 2238
3812 2238 642
3813 642 2242
3814 2242 734
3815 734 2246
3816 2246 848
3817 848 2249
3818 2249 941
3819 941 2253
3820 2253 1033
3821 1033 2257
3822 2257 1125
3823 1125 2261
3824 2261 1217
$
GENE 24 MEM ID 3825 1 F 2263 1 T 2264 1
$
$ INTERMEDIATE CONNECTION FOR SKIN PLATE
$
MEM INC
3849 68 92
3850 92 160
3851 2222 2225
3852 2225 2226
3853 2226 2229
3854 2229 2230
3855 2230 2233
3856 2233 460
3857 460 2236
3858 2236 2237
3859 2237 2240
3860 2240 2241
3861 2241 2244
3862 2244 2245
3863 2245 2248
3864 2248 851
3865 851 2251
3866 2251 2252
3867 2252 2255
3868 2255 2256
3869 2256 2259
3870 2259 2260
3871 1126 1150
3872 1150 1218
$
$
$ -----------------------------------------------------------------------
$
$ GUSSET PLATES FOR DIAGONALS
$
$ -----------------------------------------------------------------------
$
ELEMENT INC
$
4001 1 1220 3001 4
4002 4 3001 3002 7
$
4003 1231 369 373 3003
4004 3003 373 377 3004
4005 369 1234 3005 373
4006 373 3005 3006 377
$
4007 1246 760 764 3007
4008 3007 764 768 3008
4009 760 1249 3009 764
4010 764 3009 3010 768
$
4011 1261 1151 1154 3011
4012 3011 1154 1157 3012
4013 61 3013 3014 64
4014 64 3014 2220 67
$
4015 3015 449 453 3016
4016 3016 453 457 2231
4017 449 3017 3018 453
4018 453 3018 2234 457
$
```

```
4019 3019 840 844 3020
4020 3020 844 848 2246
4021 840 3021 3022 844
4022 844 3022 2249 848
$
4023 3023 1211 1214 3024
4024 3024 1214 1217 2261
$
4025 3 1221 3101 6
4026 6 3101 3102 9
$
4027 1233 372 376 3103
4028 3103 376 380 3104
4029 372 1236 3105 376
4030 376 3105 3106 380
$
4031 1248 763 767 3107
4032 3107 767 771 3108
4033 763 1251 3109 767
4034 767 3109 3110 771
$
4035 1262 1153 1156 3111
4036 3111 1156 1159 3112
$
4037 63 3113 3114 66
4038 66 3114 2221 69
$
4039 3115 452 456 3116
4040 3116 456 460 2233
4041 452 3117 3118 456
4042 456 3118 2236 460
$
4043 3119 843 847 3120
4044 3120 847 851 2248
4045 843 3121 3122 847
4046 847 3122 2251 851
$
4047 3123 1213 1216 3124
4048 3124 1216 1219 2262
$
$ ----------------------------------------------------------------
$
$  TENSION RODS
$
$ ----------------------------------------------------------------
$
MEM INC
5001 3002 3015
5002 3004 3013
5003 3006 3019
5004 3008 3017
5005 3010 3023
5006 3012 3021
$
5007 3102 3115
5008 3104 3113
5009 3106 3119
5010 3108 3117
5011 3110 3123
5012 3112 3121
$
$ ----------------------------------------------------------------
$
$ ADD HINGES FOR TENSION RODS
$
$ ----------------------------------------------------------------
$
MEMBER RELEASES
5001 TO 5012 START MOMENT  Y Z END MOMENT X Y Z
$
$ ----------------------------------------------------------------
$
$  ELEMENT PROPERTIES
$
$ ----------------------------------------------------------------
$
ELEM PROP
$
$  WEB OF QUOIN AND MITER GIRDERS
$
1 TO 88 TYPE 'SBHQ6' THICK 0.375
```

```
$
$ WEB OF VERTICAL BEAMS
$
89 TO 484 TYPE 'SBHQ6' THICK 0.570
$
$ BUCKLED SKIN PLATE
$
500 TO 1027 TYPE 'SBHQ6' THICK 0.375
$
$ WEB OF BOTTON GIRDER
$
1101 TO 1172 TYPE 'SBHQ6' THICK 0.375
$
$ WEB OF INTERMEDIATE VERTICAL GIRDERS
$
1201 to 1332 TYPE 'SBHQ6' THICK 0.375
$
$ WEB OF VERTICAL I BEAM FROM QUOIN TO PINTLE
$
1401 TO 1444 TYPE 'SBHQ6' THICK 0.32
$
$ WEB OF TOP GIRDER
$
3101 TO 3196 TYPE 'SBHQ6' THICKNESS 0.5
$
$
$ GUSSET PLATES FOR DIAGONALS
$
4001 TO 4048 TYPE 'SBHQ6' THICK 1.
$
$ ----------------------------------------------------------------------------
$
$ MEMBER PROPERTIES
$
$ ----------------------------------------------------------------------------
$
MEMBER PROPERTIES
$
$ ********* TENSION RODS ***********
$
$ 8 X 1.25
$
5002 5008 -
AX 10 IX 5.21 IY 53.33 IZ 1.30
$
$ 8X 1
$
5004 5010 -
AX 8 IX 2.66 IY 2.67 IZ 0.67
$
$ 6 X 0.75
$
5001 5003 5005 TO 5007 5009 5011 5012 -
AX 4.5 IX 0.84 IY 0.84 IZ 0.21
$
$ *******FLANGES FOR QUOIN GIRDER********
$
$ DOWNSTREAM AND UPSTREAM, 2 ANGLES 6 X 4 X 0.5, 0.375 SPACING
$
2001 TO 2044 -
AX 9.5 IX 0.79 IY 79.7 IZ 12.54
$
$ *******FLANGES FOR MITER GIRDER********
$
$ 2 ANGLES 6 X 4 X 0.5, 0.375 SPACING
$
2045 TO 2088 -
AX 9.5 IX 0.79 IY 79.70 IZ 12.54
$
$ *******FLANGES FOR VERTICAL BEAM IN QUOIN********
$
$ 7.5 X 0.55
$
2601 TO 2644 -
AX 4.125 IX 0.42 IY 19.34 IZ 0.10
$
$ ********FLANGES FOR OTHER VERTICAL GIRDERS********
$
$ 2 ANGLES 6 X 4 X 0.5 , 0.375 SPACING
$
2089 2090 2111 2112 2133 2134 2155 2156 2105 TO 2110, 2127 TO 2132, -
```

```
2149 TO 2154, 2171 TO 2176 -
AX 9.5 IX 0.79 IY 79.70 IZ 12.54
$
$ 2 ANGLES 6 X 4 X 0.5 WITH 13 X 0.375 COVER PLATE
$
2091 TO 2104, 2113 TO 2126, 2135 TO 2148, 2157 TO 2170 -
AX 14.375 IX 3.19 IY 148.36 IZ 17.04
$
$ *******INTERMEDIATE STIFFENERS ON VERTICAL GIRDERS*******
$
$ 2 ANGLES 3.5 X 3.5 X 0.375, 0.375 SPACING
$
2701 TO 2744 -
AX 4.97 IX 0.23 IY 12.89 IZ 5.73
$
$ ********VERTICAL BEAM FLANGES**********
$
$ UPSTREAM 11.5 X 0.805 FLANGE FOR IBEAM PLUS 12.5 X 0.375 SPLICE
$ PLATE ON TOP OF 0.375 BUCKLE PLATE
$
2177 TO 2198, 2221 TO 2242, 2265 TO 2286 -
2309 TO 2330, 2353 TO 2374, 2397 TO 2418 -
2441 TO 2462, 2485 TO 2506, 2529 TO 2550 -
AX 13.95 IX 15.67 IY 163.06 IZ 3.45
$
$ DOWNSTREAM
$ 11.5 X 0.805 FLANGE
$
2199 2200 2217 TO 2220 -
2243 2244 2261 TO 2264 -
2287 2288 2305 TO 2308 -
2331 2332 2349 TO 2352 -
2375 2376 2393 TO 2396 -
2419 2420 2437 TO 2440 -
2463 2464 2481 TO 2484 -
2507 2508 2525 TO 2528 -
2551 2552 2569 TO 2572 -
AX 9.25 IX 2.0 IY 102.02 IZ 0.5
$
$ I BEAM FLANGE 11.5 X 0.805 WITH 12.5 X 0.5 PLATE
$
2201 2216 2245 2260 2289 2304 2333 2348 -
2377 2392 2421 2436 2465 2480 2509 2524 -
2553 2568 -
AX 15.51 IX 9.26 IY 183.41 IZ 2.21
$
$ I BEAM FLANGE 11.5 X 0.805 WITH 2 12.5 X 0.5 PLATES
$
2202 TO 2215, 2246 TO 2259, 2290 TO 2303, 2334 TO 2347 -
2378 TO 2391, 2422 TO 2435, 2466 TO 2479, 2510 TO 2523 -
2554 TO 2567 -
AX 21.75 IX 24.50 IY 264.78 IZ 5.87
$
$
$ **********BOTTOM GIRDER *************
$
$ UPSTREAM FLANGES 1 ANGLE 6 X 6 X 0.5, IGNORE BETA AND USE PARALLEL AXIS
$ PROPERTIES
$
2825 TO 2848 -
AX 5.75 IX 0.48 IY 19.9 IZ 19.9
$
$ DOWNSTREAM FLANGES 2 ANGLES 6 X 3.5 X 0.5 PLUS 8 X 0.5 FILL PLATE PLUS
$ 8 X 0.625 BEARING PLATE
$
2801 TO 2824 -
AX 18. IX 17.41 IY 127.60 IZ 18.21
$
$ *******TOP GIRDER*******
$
$ DOWNSTREAM FLANGE 2 ANGLES 8 X 6 X 0.875, 0.5 SPACING
$
3801 TO 3824 6108 -
AX 22.97 IX 5.86 IY 332.35 IZ 69.72
$
$ INTERMEDIATE CONNECTION FOR SKIN PLATE, ONE ANGLE 3.5 X 3.5 X 0.375,
$ IGNORE BETA AND USE PARALLEL AXIS PROPERTIES
$
3849 TO 3872 -
AX 2.48 IX 0.09 IY 2.9 IZ 2.9
$
```

```
$ UPSTREAM FLANGE
$
$ 2 ANGLES 8 X 8 X 0.875, 0.5 SPACING
$
6109 6110 3825 3826 3827 -
3846 3847 3848 7002 7003 7004 7001 -
AX 26.47 IX 6.76 IY 334.23 IZ 159.16
$
$ SAME ANGLES PLUS 1 FLANGE PLATE 18 X 0.5
$
3828 3845 -
AX 35.47 IX 18.78 IY 577.23 IZ 203.77
$
$ SAME ANGLES PLUS 2 FLANGE PLATES 18 X 0.5
$
3829 3844 -
AX 44.47 IX 42.73 IY 820.23 IZ 245.97
$
$ SAME ANGLES PLUS 3 FLANGE PLATES 18 X 0.5
$
3830 3831 3842 3843 -
AX 53.47 IX 83.56 IY 1063.23 IZ 434.35
$
$ SAME ANGLES PLUS 4 FLANGE PLATES 18 X 0.5
$
3832 TO 3841 -
AX 62.47 IX 145.76 IY 1306.23 IZ 462.64
$
$ QUOIN BLOCK FLANGE - CASTING - APPX AS 8 X 1
$
7005 -
AX 8 IX 2.66 IY 2.67 IZ 0.67
$
$
$ ---------------------------------------------------------------------------
$
$  CHANGE PROPERTIES FOR TRIANGLES IN TOP AND BOTTOM GIRDERS
$
$ ---------------------------------------------------------------------------
$
CHANGES
ELEM PROP
1104 TO 1106 1168 TO 1170 3104 TO 3106 3168 TO 3170 TYPE 'SBHT6'
ADDITIONS
$
$ ---------------------------------------------------------------------------
$
$  CHANGES FOR BOX AT THE TOP OF BEAM5 BELOW TOP GIRDER
$    NOTE: THIS WAS NOT ON DRAWINGS PROVIDED BUT IS SHOWN ON
$        PHOTOS
$
$ ---------------------------------------------------------------------------
$
$ FIRST DELETE PART OF WEB AND FLANGES OF VERTICAL BEAM 5 AND
$  THE SKIN PLATE ELEMENTS
$
DELETIONS
ELEM 305 TO 308, 990 TO 993, 1014 TO 1017
MEM 2373 2374 2395 2396
ADDITIONS
$
$ ADD NEW JOINTS FOR BOX
$
JOINT COORDINATES
3501 290 48  476.375
3502 319 48  476.375
3503 348 48  476.375
3504 377 48  476.375
3505 406 48  476.375
$
3506 290 48  505.6875
3507 319 48  505.6875
3508 348 48  505.6875
3509 377 48  505.6875
3510 406 48  505.6875
$
3511 319 0  476.375
3512 319 16.5 476.375
$ 3513 319 33  476.375
$
3514 377 0  476.375
```

```
3515 377 16.5 476.375
$ 3516 387 33  476.375
$
$ ADD NEW ELEMENTS FOR BOX
$
ELEM INC
4501 544 3511 3512 545
4502 3511 636 637 3512
4503 636 3514 3515 637
4504 3514 728 729 3515
$
4505 545 3512 573 546
4506 3512 637 638 573
4507 637 3515 665 638
4508 3515 729 730 665
$
4509 546 573 3502 3501
4510 573 638 3503 3502
4511 638 665 3504 3503
4512 665 730 3505 3504
$
4513 3501 546 549 3506
4514 3506 549 552 2237
$
4515 3505 730 733 3510
4516 3510 733 736 2245
$
4517 3501 3502 3507 3506
4518 3506 3507 2240 2237
4519 3502 3503 3508 3507
4520 3507 3508 2241 2240
$
4521 3503 3504 3509 3508
4522 3508 3509 2244 2241
4523 3504 3505 3510 3509
4524 3509 3510 2245 2244
$
ELEM PROP
4501 TO 4524 TYPE 'SBHQ6' THICK 0.5  $ THICKNESS UNKNOWN - NOT ON DRAWINGS
$
$ ----------------------------------------------------------------------
$
$  ADDITIONS, CHANGES, AND DELETIONS IN TOP GIRDER NEAR MITER END
$
$ ----------------------------------------------------------------------
$
CHANGES
JOI COOR
2262 Y 50.25
2286 Y 65.38
1219 Y 28.5
2287 Y 58.76
$
ELEM INC
3195 2285 2262 2286
3171 2261 4005 1218 1150
3170 1127 2262 2260
$
MEM INC
3847 2285 2262
3848 2262 1219
$
ELEM PROP
3195 3170 TYPE 'SBHT6'
$
ADDITIONS
JOI COOR
4005  696. 7.0625 535.
4001  706.34 0   535
4002 708.69 7.0625 535
4003 712.31 17.90  535
4004 723.965 52.375 535
$
ELEM INC
6001 1217 4001 4002 4005
6002 4005 4002 4003 1218
6003 1218 4003 1219
6004 1219 4003 4004 2287
6005 2261 1217 4005
6015 2260 2262 2285
$
```

```
ELEM PROP
6003 6005 6015 TYPE 'SBHT6' THICK 0.5
6001 6002 6004 TYPE 'SBHQ6' THICK 0.5
$
MEM INC
7001 1219 4003
7002 2285 2286
7003 2286 2287
7004 2287 4004
$
DELETIONS
ELEM 85 TO 88
ADDITIONS
JOI COOR
4006 696.    7.0625 505.69
4007 708.69   7.0625 505.69
$
ELEM INC
6014 4006 4007 4002 4005
6006 1214 4006 4005 1217
6007 4006 1218 4005
6008 1218 1215 1219
6009 4006 1215 1218
6010 1215 1216 2287 1219
6011 1211 1212 4006 1214
6012 4006 1212 1215
6013 1212 1213 1216 1215
$
MEM INC
7005 4007 4002
$
ELEM PROP
6006 TO 6014 TYPE 'SBHQ6' THICK 0.375
CHANGES
ELEM PROP
6007 TO 6009 6012 TYPE 'SBHT6'
6014 THICK 1.0
ADDITIONS
$
$ ==========================================================================
$
$  CHANGES AND ADDITIONS FOR QUOIN END OF TOP GIRDER
$
$ ==========================================================================
$
$
CHANGES
JOI COOR
2264 Y 60
$
ELEM INC
3173 4104 2221 2264 69
3174 2221 2222 2265
3102 68 92 2221 4104
$
ELEM PROP
3174 TYPE 'SBHT6'
$
MEM INC
3825 4104 2221
3826 2221 2265
$
DELETIONS
JOINT 2263
$
ADDITIONS
JOINT COOR
4101 -10.34  0.0  535.
4102 -13.34  8.948 535.
4103 -16.34  17.896 535.
4104  0.   29.78  535.
$
ELEM INC
6101 4101 67 68 4102
6102 4102 68 1323 4103
6103 4103 1323 1346
6104 1346 1323 69
6105 1323 4104 69
6106 1323 68 4104
6107 2221 2265 2264
$
```

```
ELEM PROP
6101 6102 TYPE 'SBHQ6' THICK 1.
6103 TO 6107 TYPE 'SBHT6' THICK 1.
$
MEM INC
6108 4101 67
6109 4103 1323
6110 1323 4104
$
$ ---------------------------------------------------------------------------
$
$   CHANGES FOR QUOIN GIRDER TO ACCOMIDATE CHANGES IN TOP GIRDER
$
$ ---------------------------------------------------------------------------
$
CHANGES
ELEM INC
44 66 65 4104 69
$
ADDITIONS
ELEM INC
6111 65 68 4104
$
ELEM PROP
6111 TYPE 'SBHT6' THICK 0.375
$
$ ---------------------------------------------------------------------------
$
$   BOUNDARY CONDITIONS
$
$ ---------------------------------------------------------------------------
$
UNITS DEGREES
$
$ *********PINTLE AND GUDGEON PIN*********
$
STATUS SUPPORT 1301 1323
JOI REL
1301 MOM X Y Z
1323 FORCE Z MOM X Y Z
$
$ *********QUOIN BLOCK ON TOP GIRDER*******
$
STATUS SUPPORT 4102
JOI REL
4102 FORCE Y Z MOM X Y Z TH1 18.433
$
$ *********MITER BLOCK********
$
STATUS SUPPORT 4002 4007
JOI REL
4002 4007 FORCE Y Z MOM X Y Z TH1 -18.433
$
$ *********DOWNSTREAM FLANGE OF BOTTOM GIRDER***********
$
STATUS SUPPORT -
1 93 185 277 369 484 576 668 760 875 967 1059 1151 -
1220 1223 1227 1231 1234 1238 1242 1246 1249 1253 1257 1261
JOINT REL
1 93 185 277 369 484 576 668 760 875 967 1059 1151 -
1220 1223 1227 1231 1234 1238 1242 1246 1249 1253 1257 1261 -
FORCE X Z MOMENT X Y Z
$
QUERY
$
$
LOADING 1 'IMPACT LOAD OF 100 KIPS APPLIED AT JOINT 1213'
UNITS KIPS
JOINT LOAD
1213 FORCE X -31.623 Y -94.868
$
units lbs ft
$
$ pressure load corresponding to 10 ft of head over top
$ 21 ft of gate to simulate guidelines for horizontally framed
$ gates
LOADING 2 '10 FT. OF HEAD FROM 10 FT BELOW HIGH POOL TO TOP GIRDER'
ELEMENT LOAD
764 TO 1027, 4517 TO 4524 -
  SURFACE FORCE GLOBAL PY -624.
$
```

```
$ DELETE PREVIOUSLY DELETED ELEMENTS SINCE THEY WERE USED IN THE
$ ABOVE LOADING LIST
$
DELETIONS
ELEMENTS 990 TO 993, 1014 TO 1017
ADDITIONS
$
$ 120 KIP LOAD AT MIDSPAN OF TOP GIRDER
$
UNITS KIPS
LOAD 3 '120 KIP LOAD AT MIDSPAN OF TOP GIRDER'
JOINT LOAD
2275 FORCE Y -120
$
UNITS LBS FEET
$
$ HYDROSTATIC LOAD PART I - FULL HYDROSTATIC IS PART I OF PART II
$   THE LOAD WAS BROKEN UP THIS WAY IN ORDER TO USE HEAD LOADING
$   TO SIMULATE BARGE IMPACT
$
$  CORRECTED DIRECTION OF HYDROSTATIC LOADS TO GLOBAL Y 6/25/92
$
LOAD 4 'HYDROSTATIC LOAD - PART I'
ELEMENT LOAD
500 TO 643   SURFACE FORCE GLOBAL PY -1248.00
644 TO 667   SURFACE FORCE GLOBAL PY -1211.81
668 TO 691  SURFACE FORCE GLOBAL PY -1092.00
692 TO 715  SURFACE FORCE GLOBAL PY  -972.19
716 TO 739  SURFACE FORCE GLOBAL PY  -853.00
740 TO 763  SURFACE FORCE GLOBAL PY  -733.20
$
$ HYDROSTATIC LOAD PART II
$
LOAD 5 'HYDROSTATIC LOAD -PART II'
ELEMENT LOAD
764 TO 787  SURFACE FORCE GLOBAL PY  -612.14
788 TO 811  SURFACE FORCE GLOBAL PY  -494.21
812 TO 835  SURFACE FORCE GLOBAL PY  -374.40
836 TO 859  SURFACE FORCE GLOBAL PY  -254.59
860 TO 883  SURFACE FORCE GLOBAL PY  -133.54
$
$ LOADING 6 - SAME AS LOAD 5 BUT USED TO STORE RESULTS FOR ANTISYMMETRIC
$          IMPACT LOADING
$
UNITS KIPS
LOADING 6 '120 KIP ANTISYMMETRIC LOAD AT MIDSPAN'
JOINT LOAD
2275 FORCE Y -100.
$
$   SYMMETRIC ANALYSIS - LOADINGS 1 TO 5
$
LOAD LIST 1 TO 5
units inches
STIFFNESS ANALYSIS
$
$   ANTISYMMETRIC ANALYSIS - LOADING 6 ONLY
$
CHANGES
$
$   CHANGE BC AT MITER BLOCK
$
JOINT RELEASES
4002 4007 FORCE  X  MOM X Y Z TH1 -18.433
$
ADDITIONS
LOAD LIST 6
STIFFNESS ANALYSIS
$
LOAD LIST ALL
LIST REACTIONS
$
LIST SUM REACTIONS
LIST DISP JOINT 1213 1216 1219
SAVE 'MITERALL'
FINISH
```

```
restore 'MITERALL'
$
$ joints in top girder
$
define GROUP '/GP/TOPG' joints -
   67    68    69    1217  1218  1219  159 -
   160   161   251   252   253   343   344 -
   345   550   551   552   642   643   644 -
   734   735   736   941   942   943   1033 -
   1034  1035  1125  1126  1127  457   458 -
   459   460   848   849   850   851   92 -
   1150  184   276   368   483   575   667 -
   759   874   966   1058  2220  2221  2222 -
   2223  2224  2225  2226  2227  2228  2229 -
   2230  2231  2232  2233  2234  2235  2236 -
   2237  2238  2239  2240  2241  2242  2243 -
   2244  2245  2246  2247  2248  2249  2250 -
   2251  2252  2253  2254  2255  2256  2257 -
   2258  2259  2260  2261  2262  1323  1346 -
   4101  2264  2265  2266  2267  2268  2269 -
   2270  2271  2272  2273  2274  2275  2276 -
   2277  2278  2279  2280  2281  2282  2283 -
   2284  2285  2286  2287  4005  4001  4002 -
   4003  4004  4104  4102  4103
$
$ elements in top girder
$
define GROUP '/GP/ETOP' elements -
   3101  3102  3103  3107  3108  3109  3110 -
   3111  3112  3113  3114  3115  3116  3117 -
   3118  3119  3120  3121  3122  3123  3124 -
   3125  3126  3127  3128  3129  3130  3131 -
   3132  3133  3134  3135  3136  3137  3138 -
   3139  3140  3141  3142  3143  3144  3145 -
   3146  3147  3148  3149  3150  3151  3152 -
   3153  3154  3155  3156  3157  3158  3159 -
   3160  3161  3162  3163  3164  3165  3166 -
   3167  3171  3172  3104  3105  3106  3168 -
   3169  3170  3173  3174  3175  3176  3177 -
   3178  3179  3180  3181  3182  3183  3184 -
   3185  3186  3187  3188  3189  3190  3191 -
   3192  3193  3194  3195  3196  6001  6002 -
   6003  6004  6005  6015  6101  6102  6103 -
   6104  6105  6106  6107
$
$ members in top girder
$
define  GROUP '/GP/MTOP' members -
   3801  3802  3803  3804  3805  3806  3807 -
   3808  3809  3810  3811  3812  3813  3814 -
   3815  3816  3817  3818  3819  3820  3821 -
   3822  3823  3824  3825  3826  3827  3828 -
   3829  3830  3831  3832  3833  3834  3835 -
   3836  3837  3838  3839  3840  3841  3842 -
   3843  3844  3845  3846  3847  3848  3849 -
   3850  3851  3852  3853  3854  3855  3856 -
   3857  3858  3859  3860  3861  3862  3863 -
   3864  3865  3866  3867  3868  3869  3870 -
   3871  3872  6108  6109  6110  7002  7003 -
   7004  7001
$
$ define load combinations
$
loading combination 7 '10 feet of head + hydrostatic'
combine 7 2 1.0 4 1.0
$
loading combination 8 '120 k symmetric loading at midspan of top girder + hydro'
combine 8 3 1.0 4 1.0 5 1.0
$
loading combination 9 '120 k antisymmetric + hydro'
combine 9 3 0.5 6 0.5 4 1.0 5 1.0
$
loading combination 10 '120 k antisym(other leaf) + hydro'
combine 10 3 0.5 6 -0.5 4 1.0 5 1.0
$
units kips inches
list reactions
CALCULATE AVERAGE STRESSES top middle bottom ELEM GROUP '/GP/ETOP'
LIST FORCES MEMBERS GROUP '/GP/MTOP'
save 'loadcomb'
FINISH
```

REPORT DOCUMENTATION PAGE

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13. ABSTRACT *(Maximum 200 words)*

A finite element analysis of barge impact on the lower miter gate of Lock and Dam 26 is presented. The response of the structure was assumed to be linear and the barge impact was modeled as an equivalent static load. The analysis was originally intended to aid in planning full scale barge impact tests at Lock and Dam 26. Due to contract delays and the scheduled demolition of the gate, the analysis was not completed prior to testing. The results of the finite element analysis are presented and compared with the full scale test results.

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